1, Shipbuilding, 1836

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THE THEORY AND SCIENCE OF NAVAL ARCHITECTURE

FAMILIARLY EXPLAINED AND INTIMATELY BLENDED WITH THE ART.

TOGETHER WITH

OBSERVATIONS AND PRACTICAL CONCLUSIONS, TENDING TO THE FURTHER IMPROVEMENT OF SHIP-BUILDING,

AND TO THE

CONSTRUCTING OF SHIPS FOR FAST SAILING.

With Important Hints for the proper Management of Ships at Sea.

DESIGNED FOR

THE ASSISTANCE OF THE PRACTICAL SHIP-BUILDER, THE ATTENTION OF THE MAN OF SCIENCE, THE USE OF THE NAUTICAL OFFICER, YACHTSMAN, AND AMATEUR, AND FOR THE BENEFIT OF ALL INTERESTED IN SHIPPING.

The whole made easy, clear, and intelligible, to common capacities.

By ISAAC BLACKBURN,

(Late of Plymouth,)

SHIP-BUILDER.

PLYMOUTH:

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PREFACE.

THE power of Britain, the safety of her dominions, and the prosperity of her colonies and commerce, must ever depend on her shipping. The importance of ship-building to this country, in a national point of view, is therefore so evident, that any endeavour to improve the form or mode of constructing ships, must, at least, be viewed favourably by the public at large; and more especially receive the attention of all immediately interested in shipping. Moreover, with a *sailor* king on the throne of these realms, and nobles of the land becoming members of yacht clubs, with a view to promote improvement in shipping, the efforts of individuals would appear to be invited. Having had, however, an early and a strong predilection for the science of ship-building, and for experiments relating to the theory, together with a subsequent long experience in the practice of the art, and ever an ardent desire for its improvement, I could want no other inducement to use my humble endeavours, and therefore composed this little treatise, and present it accompanied by my best wishes, that it may be useful in advancing the improvement of ship-building.

It will be admitted on all hands, that publications on this difficult and obscure subject, require to be composed in such a manner as to become useful in the promoting of such improvement; and that a work in order to be most useful, should be written so as to be easily comprehended by those who seek instructions from it, especially by those who can apply such instruction to the object in view; and more particularly by the practical ship builders, since they are commonly expected to make improvements, or if not to

devise them, at least to carry them into effect in the constructing of ships. It is therefore to be deeply regretted, that the most essential parts of almost all the works published on the theory and science of ship-building are so abstruse as actually to be beyond the comprehension of those who could make the best and the most use of the instruction to be derived from them; and thus it unfortunately happens with respect to the generality of ship builders, they not being usually furnished with such an education as will enable them to understand such abstruse works: and this may be the more regretted, because by far the greater and most essential parts might be familiarly explained by plain words, and easily comprehended by common capacities, without the introduction of what appears to most readers of the subject, unintelligible characters, and puzzling calculations. Added to which, some of the works on this subject are so very costly as to be beyond the means of many aspiring talented individuals to purchase; many are very scarce, and not easily to be procured at any price; and most of the first-rate books are written by foreigners, whose languages are not generally understood. Even those books which have been written by English authors are not only incomprehensible to the generality of ship builders, but very few of the works apply the science to practical use, and even then but in a partial degree. Indeed, some of the most learned productions on the subject, both foreign and English, may be considered almost a dead letter, as it respects their general practical utility; for neither the education of the ship builders in general, (as before observed,) enables them to comprehend, nor their time afford sufficient leisure to acquire a knowledge of intricate mathematical positions and calculations, seldom having opportunity for much study, in consequence of their being so much taken up and engaged in business pursuits.

But it will be vain to expect the requisite improvements in ship-building, until the science and the art are intimately blended together; for though science, as it relates to naval architecture, may be considered in a measure as useless without the art, the art must ever continue in a degraded languishing state, without the aid of science. The application to practice, of scientific principles,

is therefore indispensable to its advancement: hence it becomes of the first importance, that the practical ship-builder should have a competent knowledge of the theory, and of the science of naval architecture; and he having so little leisure for study, a concise treatise that would convey in the most familiar way, and in the easiest manner, and afford him in the shortest time such knowledge, must of course be to him the most suitable work to resort to for instruction. And further, by the blending in such a work, scientific with practical knowledge, in a familiar manner to be readily comprehended, such work must be considered not only importantly useful, by its enabling the practical ship-builder to obtain a knowledge of the science, but also, by its affording to the scientific man some insight into the art, as well as by making it more generally beneficial to all interested in shipping.

Much obscurity is known to prevail, and loose and vague notions to be entertained on this important subject, to the great prejudice of the improvement of ship-building; and a plain work, easy to be understood, has long been considered a desideratum, and has been very much wanted to diffuse instruction, and to dissipate illusion. With such impression, the following concise treatise has been composed; and with a view to meet the means of the (equally meritorious, but) less affluent individual, the purchase of the work is rendered as easy as the expenses of printing, and other incidental charges will possibly admit of: I seek no advantage of any profits or gains whatever to myself from the publication. It is composed and presented to the public, purely from a desire and an ardent wish for the improvement of shipping; to impart knowledge to those who seek it; to those also who most stand in need of it; and to diffuse instruction where it can be made of the most important use with a view to such improvement. Its object is national benefit. To assist the practical ship-builder. To afford by a cheap tract, instruction to those bringing up to the art, and render it the young man's friend. To inform and expand the views of nautical officers and yachtsmen, and enable them to perceive in what manner the good qualities and the speed of ships may be improved and facilitated by their attention and proper management.

To promote greater accuracy in the theory; and, by affording to the scientific man practical information, to enable him to explain it to the practical man in a more intelligible way, so that the art may derive every advantage of improvement from the amendments which the man of science may achieve in the theory. And finally, to diffuse a knowledge of the science and of the art of ship-building to all of those immediately interested in its improvement, and to influential amateurs who may be desirous of becoming acquainted with this important subject.

Clearness of expression, and plainness of description, having been considered indispensable, with a view to the object of utility, such have for that reason been studiously adopted in this little tract, in which I disclaim all pretensions whatever to literary merit. The object and intention are therefore candidly submitted to the liberality of the man of letters, with a firm reliance that such will prove to him a sufficient apology for the style of the composition. It is also to be apprehended, and is without hesitation admitted, that much of what I have advanced, may not be wholly free from error; the subject being extremely perplexed and is moreover involved in considerable darkness; and on this ground the indulgence of the scientific and of the general reader is particularly invited, with a hope also, that he will excuse what may appear to him repetitions and prolixity in the work, out of consideration to its being more especially intended for the use of the learner.

ISAAC BLACKBURN.

Stonehouse, Devon,
1st January, 1836.

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INTRODUCTION.

BEFORE entering more particularly into the important subject before us, it will be expedient to make a few observations on matters intimately connected with it,—of those relative to Air, Wind, and Water,—in order that the nature of these elements, and their affinity to each other, and their respective power and effect, may be familiarly understood.

1.—Air is a compound of about one-fifth in bulk or measure of oxygen gas, to about four-fifths of azote or nitrogen gas; either mixed together by attraction, or combined by affinity, or by some means or other assimulated or kept in union, as yet not discovered or rightly comprehended. There is besides a large quantity of rarified water from the vapours ascending out of the ocean, and from the exhalations arising from the land: these abound; but are only incidently mixed with it; being alternately blended, and from condensation separated again, and discharged by rain, hail, or snow. It likewise contains heat; and that in proportion to its density: and which heat will, when the air is very powerfully compressed, almost ignite substances; and if the heat is entirely pressed out from air, it then acquires a cohesive attraction, and may be made to assume a liquid state. Air, at the surface of the sea, is about 880 times lighter than water; and the weight of a quart of common air is computed to be seventeen grains; but the weight of air, in proportion to bulk, becomes less and less the higher it is up in the atmosphere: its rarity becomes greater with the altitude.

The whole weight of the atmosphere, pressing upon the surface of the sea, is equal to about fifteen pounds upon every square inch of surface. And if air was of equal weight at every part of the atmosphere, the height of the atmosphere in such case might be assumed at five miles and a half; but the air not having the same density all the way up, but becoming gradually lighter with its altitude until it ceases to have any weight at all, the atmosphere actually reaches at least fifty miles high, and perhaps to a much greater height, though in an extreme state of rarity towards its confines to the ethereal space. The same bulk of air diminishing

in weight with its altitude, one half of the whole air in the atmosphere exists within three miles and a half up, as the air at that height doubles its volume, or the atmosphere becomes only half the weight there as at the surface of the sea. The whole pressure of the atmosphere on one inch of surface, is equal in weight to a column of water of one inch diameter, and about thirty-four feet high. Its pressure at any place is always according to the weight or height of the atmosphere above such a place; and around all bodies it presses equally in every direction.

The heat from the rays of the sun, through the atmosphere, is gradually increased as they approach the surface of the earth; they combine closer as the air increases in density; and in consequence of the heat from the sun's rays being more consolidated, the heat becomes much greater at the surface of the earth, than it is at the top of the atmosphere. Air, in its natural state, is devoid of any cohesive attraction; and as by compression the particles are brought nearer into contact, and when such compression is removed they of themselves resume their former distance, so air is proved to be of an elastic or springy nature; and the force of its spring is equal to its weight, or to the degree of compression; so likewise is its velocity in expanding: hence, when air is venting its utmost force, it will rush into a vacuum with a velocity of 1,340 feet per second.

Bodies moving in air meet with a resistance from it, and this resistance increases with the velocity, and that in the same ratio as with bodies moving through water, (see art. 15), excepting when the motion becomes very rapid, then such ratio becomes quicker in respect to bodies moving in the air, than results to those moving in water.

2.—Wind is caused by the motion of the air rushing from where there is more pressure to where there is less; as when it happens to be more rarified at one part than at another contiguous part, by the colder air advancing to occupy the place of the warmer. It is only air in its motion to obey the laws of gravity, similar to currents of water that run to preserve a level: thus when the sun's rays act upon any part of the atmosphere, that part expands, and becoming lighter than the surrounding air, mounts higher up in the atmosphere. The air which is adjacent then supplies its place. and in rushing to do so produces wind.

Wind being a fluid is subject to the same laws as other fluids; and its force according to its velocity, is, as the square of the velocity; that is to say, a wind that blows or moves three times as swift as another, will have nine times the force against the sails of a ship; and one that blows twice as swift as another will have four times the force. The force of wind, therefore, is dependant on its velocity. But it also, in a measure, depends on the density of the air at the time; and to know the exact force of the wind at any time, its velocity and the density of the air must be both ascer-

tained and calculated upon. When the barometer is up to 31 degrees, the density of the air is of course much greater than when it is down to 27 degress; and the wind may always be sensibly felt to be much stronger, more piercing, and its power greater, when the air is heavy, or when the barometer is high, than when the air is light or the barometer low, notwithstanding in each instance it might move with the same velocity.

But although wind is only air in motion, yet its strength is oftentimes prodigiously great; it has been known to uproot trees, to raise them completely from off the ground, and whirl them in the air furiously away; and the common cause of waves and the raging of the ocean, is the force, pressure, and friction of the wind on the surface of the water. A hurricane rushes with a velocity of 100 miles in an hour, and strikes with a force equal in weight to 50 pounds against one square foot of surface exposed to its violence. In a storm the wind flies at the rapidity of 60 miles an hour, and with a force equal to the weight of 11 pounds against one square foot. When its force is equal to the weight of 6 pounds against a square foot, cutters are then under their try-sails. In a brisk or close-reefed topsail gale, the wind moves at the rate of 24 miles an hour, and with a force equal to the weight of 3 pounds against a square foot. It is counted a strong breeze when it moves with the celerity of 16 miles an hour. In a stiff or topgallant-sail breeze, the wind moves along 12 miles an hour, and with a force equal to the weight of one pound on one square foot of surface. And when moving at 6 miles an hour, it is esteemed a pleasant refreshing air.

The true direction of the wind can only be accurately known, when the object that is observed with a view to ascertain it, is subject to no other motion than the wind gives it; as is the case with a weather-cock on a church steeple, or with smoke from a chimney. The vanes of a ship rarely show the true direction of the wind; for owing to the ship moving forward at the same time, the impulse of the air against the fore side of the vane tends to alter its position; and the degree of variation between the true direction of the wind, and the apparent one by the vane, will always depend upon the direction of the ship's course, to that of the way of the wind; and upon the velocity of the wind and the speed of the ship.

3.—As wind is only air in motion, so water may be conceived as air in a denser state, for water is composed of oxygen gas and hydrogen gas, in the proportion of one of oxygen to two of hydrogen, as it respects volume or bulk; and of eight-ninths of oxygen, and one-ninth of hydrogen or inflammable air, as it respects the weight of each: in which proportions these gases may, by violent pressure, or by means of the electric spark, be condensed and combined and form water; and so again water may be converted, or turned into air, by separating the gases of which it is composed.

Water has also a certain portion of atmospheric air insinuated amongst its particles; and kept in combination with it by the superincumbent pressure of the atmosphere, so as to form part of its mass: it is by this portion of air that fishes breathe; and air probably penetrates to a vast depth in the ocean, only decreasing in quantity with the depth. Water also contains a portion of heat or caloric; by which it acquires fluidity: there is heat in it, though a smaller portion of it, even when in a frozen state. Excepting fire, water is the most penetrative of all bodies: thus, when a great weight is put on a piece of dry wood, if the wood is then exposed to wet, the water will penetrate it, and even raise the weight by the absorption. In its natural state of temperature water can be expanded, either by great cold, as when turned into ice, or by great heat, as when converted into steam; and in both cases it obtains a repulsive power of great degree. It has also an attractive power, namely, the attraction of cohesion: this is evident by its collecting itself into drops, and forming its particles into spheres. Within itself, the repulsion of the heat, which it contains while in its natural state of temperature and fluidity, appears to balance the attraction of cohesion, or to equilibrate each other so nicely, so as to leave the particles to move freely about each other with but little friction: while higher temperature diminishes the tenacity of the particles. The cohesive attraction of the water-particles among themselves is very strong; for a polished needle will, if laid gently on the surface of water, float: its greater specific gravity is not sufficient to overcome the cohesion of the water-surface; and a sort of repulsive power appears to keep it in non-contact. Water is, however, extremely adhesive to most bodies; and generally there is found a degree of cohesion between a liquid and a solid: the attraction of cohesion is even greater between wood and water, than it is between water and water; hence, its adhesion to the bottom of a ship.

Water in its natural state cannot be much compressed, and is not therefore accounted elastic: that near the surface of the sea may be compressed in bulk about one hundreth part, that at greater depths not so much. Water at very great depths in the ocean, is less bulky by one-twentieth part than that at near the surface; the superincumbent pressure giving it more density: similar in effect, though not in degree, to the greater density acquired by air below from the weight of the atmosphere above upon it. The particles of water are supposed not to touch each other; and there non-contact is extremely probable; but even if they do touch, there must be vacuities amongst them, since it is known that common air can, by great force, be pressed into water when in its natural state, in certain quantities, without expanding its bulk, and be intimately blended with it Indeed, if the particles of water are round, as doubtless is the case, they, in consequence, can only touch each other but at certain prominences; and minute

vacuities must abound, into which air might have access. It is very similar to the case of round shots when piled in a heap; they only touch each other at certain points or places, evidently leaving unfilled spaces where they cannot touch each other. Hence it is, that substances may be introduced into water, which being dissolved, occupy such vacuities without enlarging its bulk: when any substances, such as sugar, salt, allum, &c., are dissolved and mixed with a mass of water, and it does not add to its bulk, it increases the weight or density of the water, as much as the articles dissolved might have weighed; but if more is introduced than the vacuities among the particles will admit, the mixture will then enlarge its bulk. Still, although a pound of salt and a pound of water when mixed will weigh two pounds, yet, when mixed, the bulk will always be much less than that of the ingredients apart. The solutions in ocean water are found to make it considerably heavier than fresh water: a cubic foot of fresh water weighs 62½ pounds avoirdupoise; the weight of salt water varies in different parts of the world from 65 to 80 pounds the cubic foot. In some confined seas it is much heavier than that in the open ocean; in others, lighter; and in some confined seas it is heavier at some seasons than at others, according as the land floods happen to abound and mix with it.

The pressure of water is produced by its weight and fluidity; and its pressure increases with its depth; and according to the depth. As for instance, it has ten times the pressure at ten feet below the surface, as it has at one foot below the surface. The lateral pressure of water is equal to the perpendicular pressure at the same depth; and at all depths it presses in every direction equally, whether the direction be upwards, downwards, or sideways.

Water will float or buoy up any substance or body that is lighter than itself. Its support to a floating body is always exerted upwards in a perpendicular direction: this will appear evident, if a floating body is put into a container that is but a little larger than its own size; it will float when the water reaches its usual swimming-mark, though only a small quantity of the fluid has access to its sides and ends; and let it be ever so heavy or bulky, a floating body will sink to the same depth, whether the mass of water sustaining it be much or little.

Every floating body when at rest, presses downward in the water, with a force or weight precisely equal to the force exerted by the water in supporting or pressing it upward; and, consequently, the quantum of water displaced by a ship when at rest, must always depend upon her weight; and hence, whatever space a ship may occupy in the water, the weight of a bulk of water that would fill that space, will be the precise weight of the ship and all she contains; that is to say, when she has no progressive motion. This may be considered as a truth of very essential importance and value to the science of ship-building; and it cannot be too strongly

impressed upon the memory. For the discovery of this solid matter of fact we are indebted to Archimedes. The buoyancy of water is in some (though usually but in a little) degree affected by the temperature of the atmosphere; and that, according as the water may happen to be more or less rarified by it. Its buoyancy always increases with its density; hence, sea water being heavier than fresh water, it is found to be more buoyant; and a ship will draw less water, or not sink so deeply in salt water, as she will do in fresh water. And hence, also, bodies whose weight will exactly sink them when at just below the surface, will cease to subside when they have sunk down to a certain depth in the ocean, owing to the increased density of water at great depths. When any substance that is heavier than water is immersed into it, such substance becomes to the lift, lighter; and will be precisely as much lighter, as the weight of the water it displaces: for instance, a pound of lead will not weigh so much as a pound by about an eleventh part, if weighed when it is in the water. For the same reason, the anchor of a ship is, when in the water, reduced in effective weight about an eight part. And thus when a man falls overboard, if he stretches his arms out of the water, he diminishes his buoyancy, and his head and body are sure to sink deeper.

4.—As some bodies are heavier, and others lighter than water, their comparative weight can be accurately represented by what the same bulk of each may weigh. Suppose the weight of a cubic foot of each of various articles to be taken; then the weight of a cubic foot of each, would be their comparative weight; or, what is called their specific gravity. This specific gravity is usually expressed in numbers, to bring them under a comparative view, or standard of comparison; common water being assumed as 1,000.

The specific gravity of the following articles used in ship-building, will then appear as—namely,—

Lead	11,325	Sea water from	1,030
Copper	9,000	to	1,288
Brass	8,000	Common water as	1,000
Steel	7,850	Dry oak	925
Iron	7,645	Dry ash	800
Cast iron	7,425	Dry elm	600
Tin	7,329	Dry fir	550
Pitch	1,150	Cork	240
Box wood	1,030		

All bodies, whatever be their specific gravity, fall by an accelerated motion, unless obstructed or resisted. Thus, a heavy body will fall 16 feet in the first second of time; in two seconds, it will have fell 64 feet; at the third, 144 feet; at the fourth second, 256 feet; and so on at that rate of acceleration. And, whatever their respective weights may be, all bodies would, if unresisted, descend near the earth's surface, through equal spaces in equal

times: the lightest body, as a feather, will fall as fast as lead in a vacuum, as is evinced when put in a tall glass receiver from which the air is extracted. Air obstructs or resists the motion of falling bodies, and fluids much more, and this in proportion as the bulk of the bodies bear to their weight: and also in proportion as the magnitude of bodies, of the same specific gravity, bear to each other. Bodies, in falling through a resisting medium, after a certain time, acquire a uniform velocity: as soon as the velocity is such, that the resistance arising from the velocity becomes equal to its respective weight, its motion can be no longer accelerated; its descent then becomes uniform, or it attains to what is called its terminal velocity; and this is soon arrived at, if the medium is dense like as water. The slowness with which bodies subside in a fluid will ever depend on the density of the fluid, and upon the magnitude and specific gravity of the bodies.

A heavy body descending in water, however accelerated by its weight, meets with a retardation: it is impeded by the water against the under part, which causes a diminution of that acceleration of motion which it would acquire, if falling in a vacuum unobstructed. Thus, also, a body lighter than water, ascending in it by the buoyancy of the fluid, moves by the same law, as a heavy body descending; that is, it is carried up by a motion accelerated; but which is retarded in like manner, by the impediment from the water against its upper part, in proportion to the velocity of its ascent. The velocity of water running out from the bottom of a container is the same as that which a body would acquire, in falling from a height equal to the depth of the container. If the container was 16 feet deep, it would issue out with a velocity of 16 feet in a second of time; if 64 feet deep, with a velocity of 48 feet per second; if 144 feet deep, 80 feet per second; and if 256 feet deep, it would gush out with a velocity of 112 feet per second.

A TREATISE

ON THE

SCIENCE OF SHIP-BUILDING,

&c., &c.

PART I.

SECTION I.

Water considered in a state of quiescence, and when disturbed.—The cause, nature, and power, of resistance.—Resistance compared with impulsion; and, also, as it relates to pressure.—Resistance against plane surfaces.—The chief element of, and what altogether comprises, resistance to a ship.—Resistance as it relates to velocity.—The operations of resistance defined as it respects ships; the comparative proportions from each operation specified; and how each bear with increase of velocity.

5.—By the laws of nature, a body that is once at rest, will remain so; it being lifeless and of itself unable to move; it persists in rest until disturbed by some force acting upon it, and which force will be stubbornly resisted by it. And a body in motion will continue in motion; being of itself unable to change, it persists in motion until stopped by some external cause, and which stoppage it will obstinately resist. This property of resistance, in matter, is termed inertia, a tendency or persistance to remain unchanged when either in a state of rest or of motion; and to either of which states all bodies are of themselves perfectly indifferent.

Hence, water being once at rest, it will remain so, unless disturbed by some extraneous force or impulsion; and, such force will, consequently, be opposed by the property of resistance which water naturally possesses to maintain itself at rest. A ship, therefore, when impelled through water, meets with obstruction from it: this is chiefly owing to the pressure of the water against the bow

and fore-body being increased by the forward motion of the ship; and it partly arises from other causes, in addition, as will be shewn hereafter. And the impediments and obstructions arising from the motion of a ship through the water, or the power which, from whatever cause opposes a ship in her forward motion, is termed resistance.

6.—This power of resistance is dependant on the velocity at which a ship is impelled through the water. By the theory of the resistance of fluids, the perpendicular or direct resistance to the motion of a plane surface through the water, *when wholly immersed*, is equal to the weight of a column of water, having the surface of the plane for its base, and for its height twice the fall producing the velocity of the motion. To explain this more clearly:—if a flat surface opposed to the water is one foot square, and its velocity through the water is 12 feet per second, then, as water in falling acquires a velocity of 12 feet per second when it has fell $2\frac{1}{4}$ feet, twice that fall would be $4\frac{1}{2}$ feet, and, consequently, the power of the resistance against the plane of one foot square, moving at 12 feet per second, would be equal to the weight of a column of water of one foot square and $4\frac{1}{2}$ feet high, which is about 282 pounds weight. In other words, a force equal to a weight of 282 pounds would impel a plane of one foot square at the rate of 12 feet per second through the water. This theory is, however, found on trial to be somewhat incorrect; the actual resistance proves to be rather less in this respect than the theory gives it.

7.—Resistance is also found to depend upon the density of the fluids: as, for instance, sea water is heavier than fresh water, and its resistance against bodies, when wholly immersed, is therefore greater; and ships also would experience more difference in the resistance from sea water, were it not that its greater density makes it also rather more buoyant; for as a ship will displace less of salt water than of fresh, she will draw rather less water, (or swim lighter,) in salt water than in fresh water; but owing to the bulk of ships being so particularly capacious at the surface of the water, it will not make above two or three inches difference in a good size ship; the surface of resistance of the midship bend would, however, be lessened in consequence of the ship being that much more out of the water; hence, the resistance as it applies to ships, may be considered to be nearly the same in sea water as in fresh water. Bodies, however, that are *wholly immersed* in sea water, meet with rather more resistance in passing through it, than they do in passing through fresh water. And bodies, moving at great depths, meet with increased resistance in proportion as the density of the water may be increased by such depths.

8.—Resistance is liable to a small variation from the degree of temperature of the water; or to its state as it respects the attraction or degree of cohesion among its particles. Water (near the surface especially) is found to be affected by the state of the atmo-

spheric air; and as the proximity of the particles of water or its degree of rarification happens to be affected by the coldness or heat of the air, a trifling difference in its resistance occurs accordingly.

9.—Greater resistance is experienced by a ship when sailing in shoal water than when sailing in deep water. By her velocity she puts the water in motion for some distance round about her; and when getting into shoal water, this motion of the water is obstructed by the ground, and a similar effect is then produced as though the water was in an imperfect state of fluidity.

10.—When water is moving against and passing by a body that is stationary, as in the case of a stream against the piers of a bridge, or of a tide against a ship at anchor, the action of the water is then called impulsion. The resistance which a ship meets with in passing through water, at any rate of velocity, is precisely equal to the impulse she would sustain from it, if she was at rest and the water moved against her with the same velocity. When a ship moves forward, the water is, by her motion against it, forced up at the bow above its level; so when a ship is at anchor, the stream being checked by the bow, the water is in like manner raised against it above its level, and exactly as much. The impulsion of, and the resistance from, water, as it respects the action of water passing a ship with a certain velocity, and of a ship moving through the water at the same velocity, may be considered in their operation and effect to be precisely the same. A stream meets with obstruction from a floating body that is moving down it; and which obstruction causes the water to rise above its level against the part of the body struck by the fluid; and, owing to this effect, a body drifting down with the stream, will go faster than the stream itself. The larger the body, the higher the water will be thus elevated against it; and, in consequence of that, large bodies will move faster, down a stream, than smaller ones: hence, a ship or a lighter will drift faster down a stream, if placed broadside against it, than when going endways. A ship sailing with the tide in her favour, may also be considered as going down hill; and her motion in a measure to be operated upon by the effect of gravity; similar to the effect when bodies are descending an inclined plane.

11.—The resistance which a body meets with, when moving through water at a depth below the surface, is not increased by the additional pressure of the water at such depth. For though the pressure of water is, at the depth of ten feet, ten times greater than it is at the depth of one foot, yet the resistance does not at all increase by such additional pressure. When a ship is at anchor in a tidesway, the stream strikes the ship with the same velocity and force at every depth; and the effect is precisely the same when she is moving, and the water at rest.

12.—The resistance against plane surfaces, (such as that of the square flat bow of a barge or a lighter,) when moved against the water with the same velocity, is, according to the theory in

proportion to the area, (or to the breadth and depth,) of the surface opposed to the water; that is, a surface of ten square feet will meet with twice the resistance as one of five square feet, &c., &c. But in whatever degree the theory may be correct, in respect to bodies in motion when they are wholly immersed, (or entirely under water,) it is not found to hold good in respect to bodies with supernatant parts, or that swim with their upper parts above the surface. The water gorged up above its level against the face of the plane, by the motion of the body, is then heaped higher against a broader surface (especially toward the middle of its breadth,) than it is against a narrower surface; and not only so, but higher than in proportion to the difference of their breadth; and the addition from this cause to the resistance from the pure inertia of the water is increased in like manner. This effect is peculiar to the motion of floating bodies swimming partly in and partly out of the water; and in which cases it has been proved on trial (at least as it respects bodies when impelled at a moderate rate of velocity,) that the resistance against broader sufaces, compared with that against narrower ones, (when equally immersed,) is greater than in proportion to the difference of breadth. Therefore, a broader area of flat surface when moved against the water meets with greater resistance compared to that against a narrower one, than in proportion to the difference of breadth; and the broader the surface, the more this difference in the resistance is augmented with breadth. This variation will appear more particularly as follows :—

When the surface is ...	9	and the resistance by experiment	9	and the resistance by theory	9
Then when the surface is	16	the resistance by experiment is found to be ..	17,53	but the resistance by theory is only	16
Do. do.	36	do. do.	42,75	do. do.	36
Do. do.	81	do. do.	104,73	do. do.	81

From thence it might be fairly inferred, that a ship having a very full bow, if built broad and shallow, would meet with more resistance than another ship (with the like full bow,) constructed narrow and deep; although the area of resistance of the midship bend should in both ships be equal. To elucidate this, suppose one ship to be 30 feet broad, and to draw only 10 feet water, and the other to be 20 feet broad and to draw 15 feet water; then 30 times 10 is 300, which is the area of resistance of the former; and 20 times 15 is 300, which is that of the latter. The area of both is, therefore, precisely equal, say 300 feet; but the one thirty feet broad and drawing 10 feet water will, from the effect pointed out, meet with the greatest resistance of the two. Thus, the same area of resistance in the midship frame of a ship might (especially if the bow is excessively full,) sustain less resistance when deep than when wide. But such effect must be taken in a limited degree,

because the water could not rise much above the level at the bow, without affecting the buoyancy, or lifting the fore-body, by which the resistance might be diminished as much nearly as it would be augmented by the heaping up of the water against it.

13.—The main obstruction to the motion of a ship through the water, or the principal element of her resistance, is the area of the immersed part of the midship bend; and hence, with the view to promote velocity, it is desirable to contract the area of the midship bend below water, as much as circumstances will admit; the resistance being in proportion to the expanse, or extent of the immersed part of the area. Having the form of the midship section, (or of dead flat,) drawn out; its area below water or its surface for resistance may be ascertained in the following manner:—measure the perpendicular depth from the water-line to the under side of the garboard-strake, (or the plank of the bottom next to the keel,) and suppose this to be 10 feet; measure also the breadth of the ship at the water-line from the outside of the plank on one side, to the outside of the plank on the opposite side, and suppose this to be 30 feet. If the bottom at the floor was quite flat, and from the bulge to the water-line at the side, it was quite upright, forming a square, similar to the bottom of a barge, then, multiplying the breadth by the depth, would produce the area of resistance, which would be (30 times 10) 300 feet of surface for resistance. But, as the floor of a ship rises, and the bulge and bottom upward to the water-line is rounding, the area will always be less than this; and that in the proportion to the difference between the curvilinear form of the bottom and a square, by ascertaining which difference, the exact area may be found.

By increasing the length of a ship, nothing is added to her area of resistance; this latter being wholly comprised in breadth and depth. Length greatly augments the capacity of a ship; and the smaller the area of resistance of ship is, in comparison to her capacity, the faster she will go; provided, such capacity does not in any other respect add to her resistance, and provided, in the form of construction, it is made to increase her power of carrying sail. But, by the reducing of the weight in a ship, although she might draw less water, and thereby have a smaller area for resistance; yet, if her capacity is reduced in a more material degree, than her area of resistance is lessened; or, if from the reducing of her weight, her power of carrying sail is materially diminished from the hurting of her capacity, she might not in consequence of that circumstance go so fast. The area of resistance is always much less in larger ships, in proportion to their admeasurement in tons, than it is in smaller ones; although the form of the midship bend and that of the body, and the proportion of their principal dimensions may be all similar. The extent of the area of resistance, is a matter of the first consideration, as it respects every ship; and its contraction of the most essential importance, with a view to lessen

resistance and promote velocity; and the difference in the resistance, arising from any difference in the form of the fore-body and after-body of a ship, would appear of much less import to her sailing than might be imagined, were such difference to be compared to the difference which a greater or smaller extent in the area of resistance of the midship bend would occasion to her sailing.

14.—The resistance which a ship meets with to her motion through the water, arises from three different and distinct causes. It arises, first, in the dividing of the water by its fore-body, or in overcoming the resistance from the inertia of the water: this, we will call the head-resistance. It arises, secondly, from an atmospheric effect: this, proceeds from a tendency to a void behind the area of resistance, while the ship is going forward; she then moves from, or forsakes the water behind the midship section. By this tendency to create vacuum, the ship has to sustain an effort at the area of resistance, or to bear a tug which checks her onward progress: this operation is commonly called, and not unaptly so, the suction; and if it may not be allowed to be a phylosophical denomination, yet as it is more familiarly understood, and more generally known to practical men by this term, and none so descriptive having been substituted for it, we will, therefore, call this operation by the old-fashion name of suction. Resistance arises, thirdly, from the friction of the water against the submerged part of the ship; accruing from the roughness of the surface of her bottom, and as emanating from the adhesion of the water to it by the attrition among the particles. Of these three causes, as it relates to ships in general, the head-resistance may be considered to be about four-fifths of the whole resistance; the suction, about the twenty-ninth part; and the friction, about the sixth part of the whole resistance. But these proportions will of course differ more or less in every ship, according to the form of their bodies, and to the degree of smoothness of the surface of their bottoms.

15.—The resistance from water increases with the velocity, or space run through. And the resistance which a ship meets with, when going at different rates of velocity, is supposed (according to the theory of the resistance of fluids,) to be as the squares of those velocities: thus, supposing the velocity to be doubled, the resistance then becomes fourfold; because there is not only double the number of particles to be removed, but the stroke against every particle becomes twice as strong. Hence, if a ship, by a certain force from her sails, goes four miles an hour, it will require four times that force to make her go double as fast, or eight miles an hour; and nine times that force to make her go three times as fast, or twelve miles an hour, &c. &c. Or, in other words, when the speed of a ship is doubled, the resistance becomes four times as great; and when her speed is tripled, the resistance is then nine times as much, &c. &c. Or at one view: namely,—

If the speed increases as	1	2	3	4	5	6	7	8	9	10
The resistance will increase as	1	4	9	16	25	36	49	64	81	100

It should, however, be here observed, in respect to the theory, that if the head-resistance, and the resistance from the suction, and that arising from the friction, be considered separately, it has been ascertained,(as will fully appear further on,) that the head-resistance increases rather more than according to the square of the velocity, (though the rates in this respect is found gradually to decrease as the velocity is accelerated;) and that the resistance from the suction, and also that from the friction, is found to increase much less than the square of the velocity.

SECTION II.

The head-resistance.—Its nature.—Manner in which the water is struck and divided by the bow; and in what direction.—Resistance as it relates to the angle of the bow.—Error in the theory pointed out, and from whence it arises.—Solid of least resistance.—Horizontal and vertical resistance.—Resistance to curved lines: error in the theory.—Curve of least resistance; and how applicable to the bows of ships.—The proper form pointed out.

16.—The head-resistance is that produced by the inertia of the water, in its opposing the motion of a ship through it. The bow strikes the water immediately in contact with it; and from the shock this water receives, it recoils, or is driven forward against that contiguous to it, and this latter against the surrounding mass; and in this manner the water is set in motion for some distance by the force of the bow. Hence, the head-resistance may be traced and defined, as partly the action of the bow against the water, and, partly, the action of the water against itself. And as the water immediately next to the bow is in a measure pushed forward by the impulse, it may reasonably be concluded, that the fore-body has less motion past the water struck, than it has past the fluid at a greater distance that remains undisturbed. The bow not only divides the water laterally, or sideways, but also in a direction as to pass over it, and in every diagonal direction. It strikes the water everywhere at right angles with its form, slant, and taper. When the lines in these various directions form an acute angle, or a sharp bow, the water struck by it is parted, and forms a course in semblance with the lines of the bow; and the curves described by the water, which is in immediate contact with, and struck by the bow, against that which is contiguous, and by the latter again against the water that is beyond it, and so on extending to where the water is at rest: these curves are supposed never to vary in form with any difference in the velocities at which a ship might be impelled.

17.—The resistance to the motion of ships varies materially

according to the degree of acuteness and obtuseness of the angle formed by their bows. A very sharp angle meets with the least resistance, and a very obtuse angle, with the most resistance, at every rate of velocity which ships sail at. A ship with a long tapering fore-body and sharp bow will invariably go much faster than one with a short taper and a bluff bow. The lines of the bow may, however, undergo many variations in their form without producing much difference in their resistance from the water, if, the midship bend continues the same: the degree of taper, or acuteness of the fore-body, ever must be governed by the bulk of the midship body, by the rising or flatness of the floor. And the resistance which the bow of a ship experiences in moving through water may be very considerably diminished by the contracting of the fore-body, and making it sharper; thus, when a ship is narrow and sharp at the midship bend, the fore-body can be contracted in proportion; finer tapering lines can then be formed forward; the bow may be made sharper and better adapted for dividing the fluid, than it can when the midship bend is broad and flat. Therefore, not only may the resistance be prodigiously diminished by contracting the area of the midship bend, but, also, by contracting the midship bend the bow can be formed to meet with materially less resistance in dividing the water. The important advantages, thus emanating, may be readily conceived, when it is considered, that the mutual action of bodies on each other are always exerted in a direction perpendicular to the touching surfaces, whether the surfaces are struck perpendicularly or obliquely. The resistance of the water against a bluff square bow, is chiefly in a direct fore and aft direction, or right against the ship's motion; while the resistance against a very sharp bow is not in a fore and aft direction; it is then, in a measure, exerted between a fore and aft direction and athwartship direction, and becomes partly sideways to the line of motion, and operates only partly fore and aft-ways; and from being less directly opposed to the ship's motion, the resistance is in consequence diminished.

18.—Unfortunately for science, there is no regular law known, that can be depended on for its accuracy, whereby to ascertain the precise difference of the resistance of water to plane surfaces, when opposed to it at different degrees of obliquity. According to the theory, the resistance of a fluid when acting obliquely on a body, decreases by the obliquity, in the proportion of the square of the angle of incidence. That is, (to explain it more familiarly,) if the water-line of the bow of a ship pointed forward to the stem, at an angle, or in the direction exactly half-way, between a line right a-head and a line right athwartships; then, according to the theory, it would meet with exactly half the resistance it would do if the bow formed an athwartship line; such as that of the square flat bow of a barge; and so in proportion with respect to any intermediate angles. But it has been proved, by repeated trials,

that the resistance is by no means as the theory states, namely, according to the square of the angle of incidence; nor according to any regular law, as yet found out. The resistance against very full bows, prove to be less than the theory gives it; and the resistance against sharp bows, is found to be much greater than the theory assigns it. Indeed the actual resistance against the bow of a ship, when very sharp, is three times more than the theory states: and the error increases enormously in proportion to the sharpness of the bow, or as the angle of incidence becomes more acute. This will be obvious, by a review of the following table.

	Angle of the bow.		*The resistance by theory.*		*The actual resistance.*
	Degrees.		Degrees.		Degrees.
Supposing	180	to be........	10,000	and to prove	10,000
Then....	168	is by theory as	9,890	but proves to be as	9,893
,,	144	,, ,,	9,045	,, ,,	9,084
,,	120	,, ,,	7,500	,, ,,	7,710
,,	96	,, ,,	5,523	,, ,,	6,148
,,	72	,, ,,	3,455	,, ,,	4,800
,,	48	,, ,,	1,654	,, ,,	4,240
,,	24	,, ,,	0,432	,, ,,	4,063
,,	12	,, ,,	0,109	,, ,,	3,999

Now, the medium angle of the bow of a ship, constructed for fast sailing, may be assumed as 48; and it will be seen by the table, that the actual resistance, in such a case, is nearly three times more than the theory makes it: and at the lower part of the bow, where the angle may be taken as 24, the actual resistance proves to be more than nine times greater than assigned by the theory. It is much to be lamented that science is no better assisted. The theory, in this respect, appears to be founded on wrong suppositions; and the error to arise from a mistaken idea of the nature of the resistance of fluids to the motion of bodies. The tenacity, or the force of the cohesion of the particles of water; their attraction and adhesion to bodies; and the friction among the particles; appear not to have been taken into account, or to have been duly considered. The errors may be traced, and the causes of them be fairly attributed, to the compound nature of the resistance to bodies, in the dividing and passing through water. This resistance, as before observed, reverts, and becomes in part the action of the water against itself; and, consequently, the degree of resistance does not solely depend on the angle or form of the bow.

The flat bow, or obtuse angle, in dividing the water directly opposed to it, becomes as it were sharpened, or rounded off, by the form assumed by the water in yielding to the force; the water driven before it gives to the flat bow a sort of appending rotundity, by which the arc of separation is chiefly formed: the mass of water is forced outward each way, by the water in contact taking

a turn round at the luff, or angle, by which the water contiguous to that in contact escapes round more freely, and the resistance of the whole mass yields more easily. Hence, bodies having obtuse entrances, meet with less resistance than assigned to them by the theory: the obstruction is thus relieved by the water itself forming an arc of separation and channel of escape, such as the form of the entrance may happen to require. It will also be equally obvious, why bodies having acute entrances meet with more resistance than the theory gives; the sharp bow forces the water off sideways; and admitting that in displacing the water just as far as the full bow, that it does so more slowly, and, therefore, with less expenditure of force, in proportion to the length of the taper, or angle, and whereby in the same degree it easier overcomes the resistance, yet, although length of angle may lessen the resistance of the water that is in immediate contact and struck by it, the acuteness does not acquire the same degree of, or even very little advantage, as it relates to the action of the water struck, in its operation against that contiguous to it, which operation is a large portion of the resistance even in respect to obtuse angles; and a most predominant portion of the resistance in respect to acute angles, since the action of the water against itself diminishes so very little with acuteness of angle: for it should be remembered, that the obstruction, or quantum of the resistance, arising from the action of the water first struck, against that of the contiguous mass, must ever depend on the expanse, or surface of the immersed part of the bow; or, which is the same thing, upon the superficial measurement of the fore part of the bottom below water; and this is not very much larger in a full bow than it is in a sharp bow.

By way of developement: suppose a full bow forming the angle of 168, (see the table,) and another very sharp bow to form the angle of 12. By computation it will be found, that the exterior surface of the immersed part of the full bow being taken as 31, the surface of the sharp bow will be as 30; or they will be in that proportion of surface to each other. Now, according to the theory, (as will appear by reference to the table,) the resistance to the sharp bow is as 0,109, while its actual resistance is 3,999; making 3,890 difference. And now particularly observe, this difference, 3,890, actually is that quantum of the resistance, or obstruction, which solely accrues from the action of the water against itself; namely, from the action of the water struck in its operation on the tenacity and friction among the particles of the contiguous mass set in motion by the impulse. Then 3,890 to a surface of 30, would, to a surface of 31, be 4,019; and which 4,019 will be the actual obstruction to the full bow, as accruing solely from the action of the water against itself. This 4,019, deducted from 9,893, its actual resistance, gives 5,874, as that part of the resistance to the full bow, arising from the shock in striking the water immediately in contact with it, in its efforts to

divide it. Thus, the resistance from the striking of the water would be as 5,874 to the full bow, and 0,109 to the sharp bow; and the resistance from the action of the water against itself would be as 4,019, for the full bow, and amount to nearly as much for the sharp bow, namely, to 3,890. The result of this developement is, that the resistance to the full bow, from the striking of the water, is 54 times as great as that to the sharp bow; while the resistance accruing to the full bow from the action of the water struck, as operating against the contiguous mass, is nearly the same, or only greater by about a thirtieth part, than that to the sharp bow.

Therefore, it is owing to the obstruction, arising from the action of the water against itself, being so nearly the same in bows of every form, or to its varying so very little with different formed angles, that the actual resistance is found to vary so much less with acuteness of angle than the theory states; or, in other words, why the resistance against acute angles is found to be so much greater than the theory assigns to them. For the obstruction, accruing from the action of the water against itself, forming so large a proportion ($\frac{4,019}{9,893}$ near three-sevenths) of the resistance against a full bow, and that obstruction diminishing so little with the acuteness of the angle, it becomes, in consequence, of most serious magnitude to a sharp bow, and lessens the advantage of its acuteness most essentially. Thus, at the medium angle of a ship's bow, two-thirds of the resistance arises from this obstruction, namely, from the action of the water struck, in its operation on that contiguous to it; while only one-third of the resistance accrues from the shock, or action of the bow against the water in contact and struck by it. And as it respects angles of extreme acuteness, this obstruction forms nearly the whole resistance; and becomes a most formidable one, when, according to the theory, resistance to such an angle should nearly vanish. Hence, it will be obvious, why the resistance against obtuse angles prove to be less than the theory gives; and why the resistance against acute angles is found to be so much greater than the theory assigns to them. The obstruction arising from the action of the water against itself, is always nearly the same with every angle; and the water will of itself ever form the easiest arc of separation and readiest channel of escape. And as it would appear from what follows, the passage of bodies with different formed entrances, is thus effected in a very remarkable manner, as in respect to the rate of velocity at which they are impelled.

The difference in the resistance against different angles, is not only much less than the theory gives us to understand it to be, but, the difference in respect to the *actual* resistance that different angles meet with, as is specified in the table, is absolutely found *to lessen as the velocity increases.* It is even opined, that bodies having sharp, or acute, entrances, only obtain more velocity than bodies with blunt, or obtuse, entrances when, by equal powers, they

are forced *slowly* through the water. And that bodies with obtuse entrances obtain even greater velocities than bodies with sharp entrances when, by equal powers, the are forced *rapidly* through the water. But, although at very rapid velocities, water may possibly assume for itself the same arc of separation, and the like form of channel may open for the admission of bodies with every varying form of entrance, yet, it should be observed, that the opinion just stated can only be entertained as it relates to the rapidity of the motions of bodies that are wholly immersed, and when impelled at much greater velocities than ships ever sail at, such as to the swiftness acquired by some fishes: for instance, that of the dolphin, which darts along at the rate of twenty miles an hour; and very probably, at such velocities, the whole of the resistance may revert to the action of the water against itself, and the form of the entrance be quite immaterial.

The solid of least resistance has been defined, by Sir Isaac Newton, as blunt-headed: the form may be compared to a tapering sugar loaf, or to that of a thick stunt wedge with its point sawn off. This, however, cannot be admitted as demonstration, but should be considered as partaking of the fallacy of the theory in respect to the difference in the resistance to the different angles, and will by no means hold good in practice. Neither is it applicable to bodies having supernatent parts.

19.—The theory further states, that the resistance of water is equally lessened, by the surface opposed to it being placed obliquely, whether it be in a level or in a vertical direction. The theory is doubtless, in this instance, perfectly accurate, so far as it relates to bodies when they are wholly and deeply immersed in the water, and science acquires value from the fact. It is not, however, correct as it relates to bodies floating on the surface of the water, such as ships. It will be proper elucidate this. When the stem of a ship rakes very much below water, and the fore-body correspondingly so, the water is, in a measure, divided in a direction for the ship to pass over it; but when the stem is upright below, and the fore-body correspondingly to it, the water is in that case divided and passed through by pushing each side of the bow against it. Then, supposing the slant of the line of the bow, or its flight upward, in one case, and the water-line round the bow in another case; present the same obliquity of direction against the water, or strike it with the same obliquity, the resistance will by no means be precisely the same, when the water is divided by the fore-body to pass it sideways, as when passing over it as according to the theory: for when the angle of a bow is formed slantingly, to deflect the water under the bottom, the resistance in such a case is found to be, in a measure, lessened by the sliding up, or rising of the bow over it. It then tends to operate more on the immersion, or to give the body a greater propensity to rise in encountering the resistance: for all floating bodies in motion have a tendency produced by their velocity to rise, or lighten up in the water.

To illustrate this effect: suppose a floating body of a similar form to a Norway prom, the fore part below the line of flotation extremely raking, or slanting, so that when in motion the fore-body, in a manner, passed over the water. If such a spoon-formed body was pulled along with a force, this rake at the fore part would, in a particular degree, cause the resistance of the fluid under it, to rise in the water; and to do so more and more, according as any augmentation of force might, by quickening the velocity, increase the resistance and upward impulse. And supposing this force to be exactly sufficient as to produce such velocity and resistance that would, by the reaction of the water, rise the body until its bottom was even with the surface of the water, the body, in that case, would skim on its bottom along the surface. The elevation would be the result of the water operating with an upward impulse; and this impulse would be caused by the velocity produced by the propelling force. Thus, for instance, at every point of its progressive motion, the body would need a portion of time ere it could settle down to its proper draft of water; but before such period could elapse, it would have been urged on to another point; at which point, the upward force of the water under its fore part would in the meanwhile have risen it higher, and so on continue to do until the due elevation of the body was attained, In a still more extreme case, the body might, by some prodigious force, be elevated and precipitated along at such a swift rate, so as alternately to touch and then not touch the water, but bound along its surface by skips, or leaps, similar to the impinging and rebounding of a cannon ball at sea, or to a stone skimmed along the surface before its force is spent and its weight sinks it. It often happens that bodies, when moving with velocity, have not time enough to produce the entire effect of their weight: thus, a waggon may be galloped along fenny ground, but if it stops it gets stugged; and, in a similar way, rapid velocities lighten the downward pressure, or bearing on the water, of floating bodies: every weight, or force, requires time to produce effect; and hence, velocity lightens pressure, A man may skate swiftly over ice that would not bear his weight if he stood still upon it, or were he to move more slowly upon it: it takes time for his weight to settle down to make the bend and fracture; and he moves rapidly from the spot he was on, to another, before the time transpires to allow the ice time to swag and break and let him through.

20.—The theory is found to be extremely inaccurate, as it relates to the resistance of water against curved surfaces, as it has been shown that it proves to be against plane surfaces. The actual resistance against curved surfaces is found to be less than is assigned to it by theory. This variation, also, is truly unfortunate for science: still, it must candidly be admitted in extenuation, that almost insuperable difficulties present themselves to the forming of a regular and correct law, for ascertaining the resist-

ance against surfaces of different degrees of fulness, or prominency. The most rounding out, or projecting parts of curves, deviate the direction of the water, and its action on the parts next struck by it; causing by its deflection the resistance against the parts in succession, to vary greatly from what it might be, if those parts were separately presented to the water in the same direction; and, in consequence of this, calculations become most difficult and intricate, and almost involved in impenetrable obscurity. No reliance can, therefore, be placed on the theory in this instance; nor, in this respect, can much assistance be derived from it. But it is found by experience, that great touchstone of truth, that too great a fulness in the bow of a ship increases resistance considerably at the velocities they usually sail at; and that a small curve meets with less resistance than a fuller curve. It is also found, that a small curve meets with less resistance than a straight line; and that a straight line meets with less resistance than a hollow line.

Mr. Emerson has attempted to ascertain the curve of least resistance, but it partakes of the fallacy of the theory, in the same manner, as the solid of least resistance described by Sir Isaac Newton. It may be remarked, in relation to the curve described by Mr. Emerson, that it must of course be supposed as intended to be presented to the water in the direction that the water would take, or in which the bow would, from its form, strike and divide the water. And as the action of the water, in being divided, always operates at right angles against the surface of the bow of a ship, consequently, this direction would, agreeable to the usual form and flight of the immerged part of the bows of ships, be a diagonal one, like that of the ribband lines. And supposing the curve in question intended to describe a ribband line, it obviously would prove too full toward the fore end, and too sudden at its junction with the midship body.

It may be observed in a general way in respect to curves, that all the lines of the bow and fore-body of a ship which lead in a diagonal direction should, below water, form gentle small curves to break in fairly with the midship body, and be no fuller near the stem than is absolutely necessary, with a view to avoid hollow level lines at, and between, the light and loaded water-line.

SECTION III.

Resistance from the suction.—How it arises, and its nature.—Its effect on a ship, and operation on the water.—Its power, and how emanating, explained.—Its effect as it relates to length of after-body. The increase of it with the increase of velocity; and the variation thereof, with different lengths of taper of after-body, and degrees of fulness.—Its operation at different depths in water, in respect to bodies with tapers of different lengths, and when moving at different velocities; and also as it relates to tapers of different degrees of fulness.—At what velocity suction is found to commence at different depths, as it relates to the length, and also to the fulness of an after-body.—Remarks on the peculiarity of the form of the after-body of a ship; the application of the science to such; and its most proper form for avoiding suction pointed out.

21.—When a ship moves forward, the equilibrium of the endway pressure is destroyed. By her motion the pressure of the water is increased on the fore-body, and decreased on the after-body, since the water behind must follow and overtake the after-body before the same pressure can be restored, and, consequently, the pressure on the after-body cannot be so great when a ship is in motion, as it is when she is at rest; and the faster a ship goes forward, the greater will be the pressure on the fore-body and the less will be the pressure on the after-body. And when a ship moves forward, the space before occupied by her after-body is filled up by the superincumbent pressure on, and by the gravity and fluidity of, the surrounding water. But the water would require time (however short the interval might be,) to put itself in contact with the after-body again, after the motion of the after-body from it: every force requires time to produce effect; there must be a lapse of time between the after-body forsaking the water, and the water coming in contact with it again; and in that interval there must, consequently, be something of, or like, space, between the after-body and the water, (however infinitely small such space may be;) and the air being excluded from such space, there would be a vacuum, (or tendency to vacuum,) and such vacated space would, therefore, be subject to the pressure of the atmosphere to fill it up.

But as the pressure of the atmosphere cannot act through the ship's bottom, to fill up any vacated space in the water, its operation in that direction would, therefore, be intercepted, and it would operate solely by pressing the water onward toward the bottom to fill up the vacuity, similar to when a void is formed between the sucker of a pump and the water, the water raises to the sucker by the pressure of the atmosphere on the surface below. In like manner, also, as the suction valve sustains an effort in creating vacuity

to enable the water to rise, so the area of resistance of a ship's bottom has to sustain an effort by creating vacuity; and this effort being made by the motion of the ship forward, it must of course be sustained by her in her motion, and is so sustained by the area of resistance as she advances forward, and by which effort her velocity becomes impeded.

It must, however, be observed, that notwithstanding the resistance from the suction emanates from an atmospheric effect, yet, the weight and pressure of the atmosphere is, nevertheless, exerted upon the water in filling up a deserted space in every direction, (excepting only in that direction where its operation is intercepted by the ship's bottom ;) but then, in whatever degree the weight of the atmosphere on the surface may add to the pressure of the water in filling up a deserted space below, the water itself can only move with a certain determinate velocity in closing on a void; hence, it requires a time to do so, while the atmospheric effect that causes the suction is comparatively instantaneous. Suction commences immediately, or simultaneously, with the motion of a body through the water, when such body happens to have no taper at the hinder part. It has been proved, by repeated trials, to take place on the least movement of such body forward, even though at the same time, the velocity of the water in filling up any vacating space has been many times greater than the motion of the body forward.

22.—And why it is so, will more distinctly appear by taking a comparative review. The suction, at the fullest part of the after-body of a ship, as sustained by the area of resistance of the midship bend, is found to be equal in power to a weight of *seventeen* pounds against one foot of area, when she is going at the rate of eight miles an hour; while the weight of the pressure of the atmosphere on a vacuum is equal to above *two thousand* pounds on a square foot; and the velocity of the water, in closing on a vacated space, at that part of a ship, is only *fifteen* feet per second, while that of air rushing into a void is above *thirteen hundred* feet per second. It cannot be supposed, considering those vast differences, that any real void is ever formed in the water by the velocity of a ship ; her motion merely causes a tendency to vacuity, producing only a degree of attenuation, or rarefaction, in the water that is pressed onward behind her, a rarefaction, or thinness, more or less, according to the degree of rapidity at which the after-body forsakes the water: which rapidity must always depend upon the rate of the velocity of the ship, as upon her velocity also depends the stress of the effort, or tug, sustained by the area of resistance in producing the degree of tendency to vacuity, or which is the same thing, the degree of suction. A void certainly might be left behind a body when rushing through the air; its motion may be so swift that the surrounding pressure might not suffice to impart a sufficient velocity to the medium for filling up a deserted space

behind it; and in such case a statical pressure on its area of resistance takes place, equal to the whole weight of the atmosphere in addition to the resistance from the air: this is precisely the case with a cannon ball which leaves a void behind.

23.—The force to fill up a deserted space beneath the surface of the water, is equal to the pressure, or weight of the atmosphere, and to the weight of the water above the vacated space added to it. For instance, the pressure of the atmosphere on the surface of the water, is equal to the weight of a column of water of about thirty-four feet high; and, therefore, there must be double the pressure to fill up a vacuity at the depth of thirty-four feet in the water, as there is at close below the surface; and at seventeen feet depth, one and a half as much pressure as at close below the surface. And the effort of the water in closing on a deserted space below, arises from the pressure of the atmosphere upon its surface, in addition to the weight of the water itself that is above such deserted space; by which efforts the upper parts of the water press and gravitate on the lower parts; and from which pressure and gravitation, and by the fluidity of the water, it acquires *velocity* in filling up a vacated space. This velocity is a certain determinate velocity at every particular depth, according as the distance of the vacated space may happen to be from the surface of the water. In closing on a vacuity, the water forces itself in every direction; and with equal velocity in every direction at the *same depth*. But then this velocity increases with the depth: the velocity becomes double at four times the depth; and is in such ratio accelerated at greater depths. In order to ascertain the velocity at which the water closes against the after bodies of ships at any particular depth, multiply the depth by $64\frac{1}{3}$, and the square root of the product will be the velocity per second. Supposing it was required to know the velocity at 10 feet deep: then multiply 10 by $64\frac{1}{3}$, which gives 643; and the nearest square root of 643 is 25, (25 times 25 being 625.) And 25 feet per second of time is, therefore, the velocity at which the water closes on the after-body of a ship at 10 feet below the surface.

Thus, the water in closing on the after-body of a ship acquires, by pressure, weight, and fluidity, a velocity; and its motion in filling a vacated space is in every direction. It has a motion to follow the body, to pass the body, to move sideways against the body, to move upward, and downward, and obliquely; and in all directions, excepting only in that where its influx is intercepted by the ship's bottom. Its greatest effort in closing is met by the after-body in the direction between that of passing, and that of moving sideways against the body; or in a similar direction to the tapering line of the after-body. When a ship is sailing fast, the closing water strikes the after-body in a direction more as passing it; and when she goes slowly, more in a sideway direction toward it. If the after-body of a ship is not formed sufficiently tapering,

or clean in the run, to admit the water, by its natural velocity to close against it, and pass entirely away, she will, in addition to the head-resistance, have to sustain a resistance, effort, or tug, at the midship bend, equal to the weight of a body of water of such bulk as would fill all the vacuities, or be sufficient to give due density to any attenuation in the fluid collected within the space between the after-body and the line of direction which the water naturally takes in passing from the midship bend to where it closes: thus, a boy cannot with a sucker create a vacuum to lift a stone without a tug equal to the weight of the stone. It is obvious, from what has been shown, (see art. 22,) that no real vacuum can ever be formed by the progressive motion of a ship at the rate they are impelled at; but this space is filled up with rarefied water attenuated by the suction (usually called dead-water,) urged on after the ship by the gravity and fluidity of the surrounding mass, and by the superincumbent pressure of the atmosphere.

24. The suction operates more powerfully when a ship has a short after-body, than when she has a longer one, since the greater length affords more time for the water to close and impinge against a longer taper of after-body than against a shorter one.

In almost all instances the suction is found to increase with, and according to, the shortness of the taper of the after-body: the longer it is, the less will be the suction; the closing water then having more time to come nearer in contact with the taper, it thereby makes the vacated space smaller, and diminishes the suction. When the taper of the after-body is not only long enough to allow a sufficient time for the water to close against every part of it, but also to impinge and press against the taper, with a degree of pressure equal to the unsustained pressure, or to that which the after-body loses by the forward motion of the ship, the resistance from suction then vanishes, and the tendency to vacuity, and the stress on the area of resistance, or the tug in producing it, ceases altogether. In thus operating, the closing water acts obliquely on the taper of the after-body, tending to press it forward: precisely like the wind acting obliquely on the sail of a ship when set obliquely to it, since in all cases the mutual action of bodies on each other are always exerted in a direction perpendicular to their touching surfaces, whether the surfaces are struck perpendicularly or obliquely.

When the taper of an after-body happens to be so short, and of such a peculiar form as to cause the water in its course from the midship bend to be deflected against the closing water, so as to check it in its way to close laterally on the taper, there is then a considerable resistance added to that of the suction, and altogether a much greater impediment to the velocity of a ship is then created than if there was no taper whatever. This length and form of taper should be carefully avoided in laying down ships. It may be known by the following representation of it: whenever

the taper of a diagonal line aft happens to be in length (measuring from where the taper commences to where it terminates at the stern-post,) exactly twice the half breadth as taken from the middle line at where the taper commences, and the line turns suddenly at where it commences, then this highly disadvantageous effect will assuredly be produced.

25.—The suction increases as the velocity of the ship through the water is increased; but it is found to increase in a less ratio than the head-resistance; and also in a smaller ratio than the duplicate ratio, or as the square of the velocity. It is ascertained to increase rather more than three times ($3\frac{1}{4}$ times) with double the velocity; and rather more than seven times ($7\frac{1}{4}$ times) with triple velocity. As for instance, if a ship going five miles an hour sustained a certain resistance from the suction, she would, when going ten miles an hour, sustain three times as much resistance from it. Or again, if a ship going three miles an hour sustained a certain resistance from the suction, she would, when going nine miles an hour, sustain seven times as much resistance from it.

26.—It has been explained in another place, (see art. 23,) that water when closing on a deserted space, at any particular depth below the surface, always moves with a certain determinate velocity according to, and depending on, the depth. This ever will be the case, let the velocity of a ship through the water be what it may. If, therefore, when a ship is sailing five knots an hour, the water by its natural velocity had just sufficient time to close and impinge efficiently on her after-body, then, consequently, when going at ten miles an hour the water could only have half sufficient time to do so. Hence it follows, that the taper of an after-body of a ship might be long enough when she is going at a slower velocity, and yet prove too short when going at a greater velocity. And hence, also, the inference, that the water might have sufficient time to close and impinge on a short after-body when a ship is moving at a slow rate, and yet not have sufficient time to close and impinge against it when going at a greater velocity. And, consequently, a ship that is intended to sail very fast, will require a longer taper of after-body than another not intended to sail fast, and a cleaner run also, with a view to facilitate the influx of the water into the space which, as she advances, she continually leaves behind her. So also, it may be remarked, as it relates to the different effect of the deflection of the closing water on the curve, (or the degree of rounding out,) of the tapering lines of the after-body of a ship as operating with difference in her velocity. A swell, or deviation from a straight line, in the taper of the diagonal, or ribband lines, (which is nearly the direction the closing water takes along the flight of the after-body,) is found to create suction, or to be an impediment to velocity, when a ship is going fast through the water. It is, however known to be a smaller obstruction in slower, than in quicker motions. It may even prove no hinderance to her velocity in

slower motions, and yet, in quicker motions, become a considerable impediment. Indeed, a small curve, or swell, may promote head-way in very slow motions, although, in quicker motions, it becomes a material obstruction.

From hence it is obvious, that the faster a ship is intended, from her construction, to sail, the longer the taper of the after-body should be, the less should be the curving of the taper also, and the cleaner the run in all respects. It is equally obvious, also, that such length of after-body, as might be exactly suitable to a ship intended for fast sailing, would be longer than needful to a ship not intended for fast sailing. And it may be here remarked, that when the taper of an after-body is longer than requisite to avoid suction, at the time when a ship is going at her greatest speed, there is, in such instance, an increase of resistance by the friction of the water against the superfluous length, and this superfluity of length sometimes adds but very little to her capacity. Yet, on the other hand, it should also be remembered, that as the water would act more powerfully on the rudder, the ship steer better, and also makes less lee-way by the having such additional length: it may, therefore, be considered, upon the whole, an acquisition to all ships rather than a disadvantage.

27.—It has been shewn, (see art. 23,) that water in its efforts to close on a deserted space, always moves with a certain determinate velocity at any particular depth, but that this velocity increases with the depth. The suction will, of course, vary accordingly, and, consequently, the resistance. This circumstance claims particular observation and attention, since, whatever may be the length of the taper of the hinder end of a body moving through water, the suction will always be greater when such body moves with its upper part just even with the surface of the water, than when moving at any depth below it; or, in other words, a body will from this cause meet with greater resistance near the surface of the water than at greater depths; or, there will in fact be more resistance to a body when moving at the surface, than to the same body if deeper immerged. It must be obvious, that this very interesting circumstance is to be entirely attributed to the velocity of the water increasing with its depth; or to its influx behind a body being more accelerated in its closure, when deeper immersed by the greater superincumbent weight and pressure, by the which the suction is diminished. And it may be added, when the body is deeper immersed, the water pours into the space left by the body as it advances, from *above* as well as from below and sideways, by which its influx is still further facilitated.

A very important circumstance consequent on the velocity of water in its closure on a deserted space increasing with its depth, here presents itself for contemplation, as it relates to the form of ships. It is evident, that though the velocity of water, at a small depth, might be insufficient to close and impinge against a short

taper, yet, if the same taper was at a greater depth, its velocity might prove quite sufficient to do so; and that a taper might be long enough at a certain depth in the water, and yet prove too short at a lesser depth. Therefore, as the water requires more time to close on a vacated space which is near the surface, than it does on one at greater depths; and a long taper affording the more time for the water to close and impinge against it; it follows, that the taper of the after-body of a ship ought, speaking scientifically, to be longer toward the surface of the water than at greater depths. It happens, however, that the draughts of ships are designed quite the reverse way: ships are, in this respect, constructed on a principle diametrically opposite to that, which the action of the fluid points out to be proper and requires, since the immerged part of the after-body of a ship is always fullest, or most rounding out at, and close below the surface of the water, and most tapering at the lowest part; the run gradually becoming longer and cleaner, the nearer it approximates to the keel. It must, however, be observed, notwithstanding, that although this form of after-body is so contrary to scientific principles, yet, it cannot very well be avoided; since, if the buttock of a ship was to be taken away, she, in consequence, would lose her support aft: and many bad properties would emanate from such construction, highly prejudicial, and of fearful effect.

28.—The ratio in which the suction increases, with increase of velocity, has been pointed out: (see art. 25.) In respect to which, it is here to be observed, that when the taper of the line of the after-body is long and straight, and the suction in consequence very trifling, the impediment from suction will become much less from any increase of velocity, than it will be when the taper is short and full. With a view to be more explicit: suppose in one case, a ship to have a fine clean run, and when going five miles an hour, the impediment from the suction to be as 1; then when she goes ten miles an hour, the suction will then be three times as great, this would be 3; and the increase of suction in this case will be only 2. But supposing, in another case, a ship to have a full run, and when going five miles an hour, the obstruction from the suction to be as 4; then when she goes ten miles an hour, the suction (becoming three times as great) will be 12; and the increase of the suction would, in this case, be as much as 8. Thus, by doubling the velocity, the suction in the former case only increases 2, while in the latter, it increases 8. This circumstance claims much attention, and shews how studiously every degree, and especially any inordinate degree of suction, ought to be avoided, and what care is required in forming the tapering lines of the after-body, when laying down a ship; for a full after-body not only has a larger bulk of broken, or dead-water, accompanying it in its motion than a fine tapering one, but this bulk increasing with each, in the same ratio with increase of velocity: that accom-

panying the full after-body becomes of a magnitude prodigiously more enlarged, than that of a fine tapering one; and the resistance from the suction increased in a corresponding degree.

29.—Referring to what has been said, (see art. 21.) The suction does not commence (as it relates to a ship,) until after she attains a small velocity, owing to the after-body having a taper: nor does it commence at the same time at every part of the after-body of a ship. For instance, it commences first of all at the fullest part, and at that portion of the fullest part which is nearest the surface of the water; but lower down where the lines of the run have a longer taper, it will not commence sometimes until the ship has acquired a velocity of perhaps five or six miles an hour; and at the lowest part of the run, where the lines are straight and have a fine taper, there may be no suction whatever, even when a ship is sailing at her greatest speed. The length and fineness of taper, therefore, not only gradulates the degree of suction, but upon that depends also the time of its commencement, or at what velocity the ship must sail at before the suction will begin.

When the taper of a line in the after-body is very long, and it happens to have a small curve, or to deviate in a small degree from a straight line, and the suction does not commence on it until the ship has reached to a velocity of five or six miles an hour. After the suction has began, it is found to increase in a greater ratio with increase of velocity, when the taper has a small curve, than when it is quite straight, owing to the deflection of the closing water in passsing along the curve.

Whatever may be the velocity of a ship, at the time when the suction first operates on any particular part of her after-body, it always increases with increase of velocity, in the ratio of at least three-fold with double the velocity. And although by a certain length and fineness of taper in the after-body, suction may in a great measure be avoided in ships, at the velocities to which they usually attain, yet, in respect to other description of bodies that are wholly emerged, and moving in the water with greater rapidity, there is no length, or fineness of taper, can be given, but that at some certain rate of velocity a suction will commence, and then increase with increase of velocity, in the ratio before-mentioned.

As it relates to ships in general, the resistance from the suction may be considered to be about the twenty-ninth part of the whole resistance opposed to her motion through the water. It is, however, subject to a trifling variation from the changes in the density of the atmosphere.

30.—The contour of the after bodies of ships, necessarily, being the very reverse to that form which is best adapted for avoiding suction, (see art. 27,) every endeavour should be studiously made, to apply scientific principles as far as can possibly be assimulated with such figure of construction. On surveying the after-body of a ship, it will appear evident, from the irregularity of its form,

that the water must naturally take multifarious directions in closing upon it. In some parts to impinge more in a level direction, in other places, more perpendicularly; and in other parts, in a direction between a level and a perpendicular, or in a diagonal direction, similar to that of the ribband lines. The water will in its restitution naturally take that direction by which it can close with the most facility. It will ever follow the flight of the after-body; under the buttock it will rush upward to restore itself to a level; and in every part impinge at right angles against the surface of the bottom.

The judicious draughtsman will observe a due precaution in laying down the after-body of a ship, that the lines leading in the direction which the water will naturally take in its closure, may in every such direction be fair and with as little fulness, or swelling out from a straight line, as circumstances will admit; and above all things, to avoid any fulness toward the ending of the lines. They should break in with a fair curve at the midships; continue less curving more aft; and become quite straight for some distance before they terminate at the stern-post. And where they diagonally intersect the upper water-line under the buttock, a small hollow in the diagonal line just below such intersection would present a very suitable form for admitting the water to pass clear away and fly off; and which hollow would be desirable, if it could be brought in fair with the form of the body above. The diagonal ribband lines aft, may generally be considered the most proper ones to adopt in laying down a ship, since they pretty nearly assume the direction which the water will naturally take in its closure on the after-body. Some of these ribband lines terminate at the stern-post, and other of them terminate on the stern-frame: a fulness in the water-line at where these ribband lines intersect it in a diagonal direction under the buttock, will be found rather an advantage than otherwise, by its lengthening the taper of the diagonal lines at the surface of the water. This water-line must, however, be understood as the one formed by the ship when in sailing trim. A square tuck (for smaller vessels especially) is with this view preferable to a stern-frame; taking care, however, to station the lower part of the tuck at such height as to be flush, or even with the surface of the water, and to give it such a form, that when the ship heels under sail, no part of it may ever be in the water to cause a drag, but merely just to skim the surface as she goes along.

31.—The pre-eminent advantage of contracting the area of the midship bend below water, and of such recourse being the most effectual means to lessen the head-resistance, has already been elucidated: (see art. 17.) By the very same measure, the suction is also lessened: a larger area of resistance occasions more suction than a smaller one, in the proportion to the difference in the area. Besides, not only in this degree is the suction lessened, but the

midship body, by not bulging out so much, gives the lines of the after-body a more acute taper, and admits of a corresponding degree of lankness in its form; and by thus producing a cleaner run, the suction is still further diminished.

SECTION IV.

Resistance from the friction of water.—How it arises.—Its variation as it respects smoothness of surface.—Not altered by difference in the pressure of water.—Increase of, with respect to extent of surface, and with respect to increase of velocity.—Its operation on the fore-body of a ship, and on the after-body.—And the impediment from it on the bottoms of ships, and on smooth surfaces, specified.

32.—The resistance to the motion of a ship, arising from the friction of the water against her bottom, proceeds almost wholly from the obstruction the water particles meet with, by striking against the roughness and unevenness of the surface of the bottom; and in some measure also, from the attraction and cohesion of the water. There is, in this latter respect, an adhesion of water to the ship's bottom from its being in contact with it; the attraction of cohesion between water and wood being greater than that between water and water; and whenever a ship is in motion, the water so attracted and adhering to her bottom, is operated upon by an attraction of cohesion to the mass, or by the tenacity or force of cohesion of the water in contact, to the water so attracted and adhering; and which causes a constant attrition of the water against itself,—namely, the friction of the particles of the water passing the ship against those attached to her bottom.

33.—The friction varies very materially, according as the bottom of a ship may be more or less smooth, rough, or uneven; and still more so, in respect to its being clean or foul. By paying the bottom over with oil, not only would the friction against the roughness of its surface be very much lessened, but that arising from the friction among the particles of water would be entirely annihilated; since no water could adhere to the bottom in consequence of oil being upon it, there being no affinity between oil and water to cause combination. Thus it is, that the bodies of fish being constantly smeared with an oil exuding from them, they thereby escape friction, the adhesion of water to their bodies is prevented; the cohesive attraction intercepted; and a degree of repulsion even takes place that, in other respects, eases the resistance of the water against them.

34.—Mere contact is doubtless quite sufficient to induce the adhesion of water to a ship's bottom, without much pressure. And if the quantum of the friction against any part of it depended upon

the degree of the pressure from the water, it might, in such case, be expected to be greater at the lower part of a ship, or lower down in the water, than nearer the surface, and that in proportion to depth. But, as friction is known not to vary a great deal with increase of depth, (at least as it relates to the depths to which ships swim down,) it is evident that the particles of water, in causing the friction on the bottom of a ship, operate with very nearly the same degree of force, and in the like manner, at every part to such depths. Bodies, however, moving through the fluid at vast depths may, in consequence of the greater density of the water below, sustain more friction.

35.—The amount, or quantum of friction, depends upon the extent of the surface exposed to it: the larger the surface, the more the friction. It ever will be according to the length, breadth, and depth, of that part of a ship which is under water; or, in proportion to the number of superficial feet which that part of the bottom of a ship may measure. Two ships of the same breadth and draft of water, but one being longer than the other, the longest one will, therefore, have the most friction; and, consequently, the friction will form a greater proportion of the whole resistance, if a ship is long than if she is short.

36.—Friction increases as the velocity of a ship through the water increases; or, the greater the velocity, the more the friction. But then it increases with velocity, in a less ratio than the head-resistance is found to do; and also in a lesser ratio than the duplicate ratio, or as the square of the velocity. It increases in a ratio more similar to that at which the suction increases with acceleration of velocity: (see art. 25.) The friction is found to increase three and a half times with double the velocity. There is, however, in this respect, something rather peculiar as it relates to friction: this ratio gradually lessens as the velocities become more rapid. For instance, if a ship when going *two* miles an hour sustains a certain resistance from friction, she will, when going at double that velocity, (say four miles an hour,) sustain *three and a half* times more resistance from the friction. But if a ship going *four* miles an hour sustained a certain resistance from friction, she would, when going at double the velocity, (say eight miles an hour,) sustain then only *three times* as much more resistance from it. It is probable this peculiarity may emanate from that portion of the friction that takes place against the water which adheres to the bottom of the ship: this portion of the friction, it being the action of the water against itself, may, very probably, be subject to less variation with increase of velocity, than that of the action of the water against the roughness and unevenness of the surface of the ship's bottom. The quantum of the increase of friction, from an equal increase of velocity, is found to be much the same at every varying depth in water to which ships swim.

37.—The degree of friction on the bow of a ship, in respect to

whether the bow is very round or whether it is very sharp, is found to be pretty nearly the same, it depending on the extent of the surface in a great measure, and that does not vary much. When the after-body of a ship has a very long taper, and the water closes pressingly against it, the friction is then greater than it would be if the taper was shorter, and the water merely attinged against it; that is, supposing the velocity of the ship, in both cases, to be the same. The friction arising from the roughness and unevenness of the after-body operates all over it, excepting only at those parts where dead-water happens to be accumulated, and urged on after the ship; at which parts the friction on the bottom is intercepted by the dead-water; and it reverts to an attrition of the closing water against the dead-water: no friction then arises there from the roughness of, nor from the adhesion of the water to, such parts.

38.—The resistance from friction oftentimes becomes a paramount obstruction to the forward progress of a ship. As, for instance, when the bottom gets very foul, covered with marine grass, polypus, barnicles, sea weed, muscles, oysters, &c. &c., the impediment to her velocity, from the amount of friction against such accumulations, often become even greater than the resistance she meets with from every other cause whatever. This was formerly experienced to be commonly the case with ships during long voyages, before recourse to the admirable expedient of coppering their bottoms took place, to prevent such adhesions and vegetation on them. The quantum of friction on the bottom of a ship must always depend on the degree of its smoothness and cleanness. While smooth and clean, or when coppered, the resistance from friction may, in general, be considered to be equal to about one-sixth part of the whole resistance a ship meets with. But by oiling over the copper on the bottom, it becomes materially less than this proportion.

The amount, or quantum of the friction of water against a surface placed parallel to the line of its motion, supposing such surface to be smooth and even and free from slime or any foulness, is equal to the weight of about half a pound on one square foot of the surface when impelled through the water at the rate of eight miles an hour. But the degree of friction, at *any* rate of velocity, must depend on the position of the surface with the action of the water, as upon that would depend the force wherewith the particles of water would strike it. The friction is greatest when the surface is placed obliquely against the water, (similar to the bow of a ship,) and most so when at the obliquity of 54 degrees. It becomes less when the surface is placed parallel to the line of motion (like the midship part of a ship,) than when in an oblique position against it; and least of all when placed in a direction from the line of motion, (as are the tapering lines of the after-body of a ship.) The degree of variation in the amount of friction in such

respects is, however, most difficult to ascertain. We evidently witness the difference upon the copper on the bottom of ships, which usually is worn away sooner round the bows, and along midships, and upon the dead-wood, than at any other parts.

SECTION V.

The total resistance to a ship described.—From whence it emanates; and how, as it relates to the form of the fore-body and the after-body, to the suction and the friction.—Observations.—Its variation from the theory, and causes, explained.—Affected by an atmosphere of water; how that arises, and moves with the ship, and at what comparative rate; proofs adduced.—Quantum and extent of this atmosphere of water considered and illustrated, and its varying velocity; and in what manner it operates on the fore-body, and on the after-body, and on the friction.—The difficulty of ascertaining any regular law for the total resistance of ships at different velocities.—A table of such for practical assistance; and explanation.—Resistance of water compared to the force of wind in giving velocity.—Other properties required from the form of ships besides fast sailing, and to be afterwards treated on.

39.—It will now be proper to take a collective view of the different causes of resistance as it respects their combined operation in producing the *total resistance* which a ship meets with in her motion through the water. The preceding sections have shown, that it emanates from the head-resistance, (or the opposition from the pure inertia of the water,) from the suction, and from the friction; and have also shown, that the quantum of the total resistance any ship meets with, depends on the expanse, or extent of the area of the immersed part of the midship bend, (which describes the bulk of water to be divided;) also upon the form of the bow, and upon the form of the after-body; as well also as upon the degree of smoothness or roughness of the surface of the bottom. It must be manifest, that if a ship has a rising floor and a small area of midship bend, she must sustain less resistance than if she had a flat floor and a larger area of midship bend. And if her bow is sharp that it must be less resisted than if very full, or bluff. And no less obvious, that a fine tapering clean after-body must cause less impediment from suction than a full, or bulky after-body. Nor is it less evident, that when the bottom of a ship is smooth and clean, it must meet with less obstruction from friction than if rough and foul. And from the sequel it appears that the total resistance depends much upon the degree of the smoothness of the bottom; much more so upon the form of the bow and after-body; and most of all upon the magnitude, or expanse of the area of the immersed part of the midship section.

40.—The total resistance, as it relates to the curving of the lines of the fore-body, when brought into comparision with the same curving of lines on the after-body, require observation in this place. A ship, with a full body forward and a lean hollow body aft, will go faster than if she had a lean hollow body forward and a full body aft; and for these reasons, the hollow forward, makes the line of the bow more obtuse a little abaft the hollow, and occasions even more obstruction than if the line went in a straight direction to the stem and filled up the hollow. While a hollow line aft is, in most instances, corresponding to the course of the closing water, and in accordance with its action in preventing suction. An inordinate degree of fulness aft will occasion even more resistance from suction than the additional resistance would amount to which such fulness would cause at the bow, supposing the bow had previously formed a fair curve and such fulness had been added to it. And why a fulness in the after-body often contributes more to the total resistance of a ship, than the same degree of fulness attached to the bow, can be easily explained. Thus, when the after-body is tapering, long, and fair, and the fulness is at the bow, the water being then divided by a circular fulness forward, more speedily acquires, in its way aft, a direction parallel to the direction of a long tapering after-body; and, in consequence, the closing water is not impeded in its influx by any deflection of the water in its course from forward, and no obstruction arises from such effect. On the other hand, if the after-body was full, or the taper short, and the bow was very sharp, the operation would be different. The water, in reaching the midships, would be deflected in a more outwardly direction, when coming from a sharp bow, than it would be in moving round a full and circular one; while the closing water must of necessity take a more sideway direction in its influx to fill in behind a short taper, or full after-body, than when impinging against a long taper, or fine after-body. The water from forward taking, therefore, a more outward direction, and that aft, moving more inward, or in a sideway direction, the water from forward is deflected against the closing water, and checks it in its way to fill in behind the full after-body, and, in consequence, a prodigious suction accrues. The advantage of having the fulness of body forward and the lankness abaft, is admirably illustrated by the inimitable form of the fastest swimming fishes: nothing can transcend the symmetry and beauty of the form of their bodies; their fine circular heads, and long tapering tails; and which may be viewed as one of the innumerable instances of consummate wisdom, displayed by nature to man for his instruction.

41.—The total resistance of ships, as it relates to their form and proportion, is also, in a measure, varied, by the operation of the friction in respect to difference of form and proportion. It is found that a continuation of breadth from midships, aft, or a line parallel to the line of motion, increases resistance, from the friction acting

stronger against it in that direction than it would do if the breadth diminished from midships, and formed a tapering line. And if the taper of an after-body happens to be, when a ship goes at her greatest speed, longer than is required to avoid suction, an increase in the amount of friction then arises, and that in proportion to the superfluous length, and the total resistance is accordingly augmented. And any portion of the body of a ship, that is longer or deeper than is requisite, increases the total resistance in respect to friction, by as much as the quantum of the friction on such superfluous length or depth below water amounts to. Notwithstanding, however, there arises an increase in the total resistance, in these instances, from friction, it should be remembered that very superior advantages accrue in other respects, as have been pointed out: (see art. 26.)

42.—According to the theory of the resistance of fluids, the total resistance which a ship meets with, in passing through water, should regularly increase in the ratio of four times with double velocity, nine times with triple velocity, &c., &c. There are, however, certain appending causes, that occasion a variation from the theory: partly arising, in consequence of that part of the total resistance which is caused by the suction, and that produced by the friction, each increasing in less than the duplicate ratio; and partly, also, as will appear from other circumstances. When a ship is sailing at the rate of only two miles an hour, she then meets with four and half times more resistance from the water than she sustains when going one mile an hour: in this case the resistance happens to increase above the ratio. Again, when a ship goes ten miles an hour, she meets with rather less than four times more resistance than when going five miles an hour: in this instance, the total resistance increases less than the ratio; and this variation may be attributed to the resistance arising from the suction, and to the resistance produced by the friction, each increasing less than the duplicate ratio. But the ratio is always found to decrease a little, and gradually so as the velocities become more rapid; and that partly in consequence of the peculiarity of the ratio decreasing as the velocities become more rapid, in respect to that part of the total resistance accruing from the friction, (see art. 25 and 26;) and it arises partly also from the effect of velocity on the depth of immersion.

If ships could sail at more rapid velocities than they now do, or were they to be forced through the water by other contrivances, than by sails, (see art. 117,) the total resistance would be found to increase in a much less ratio, with increase of velocity, than the theory gives; for it should be remembered, (see art. 21,) that not only the equilibrium of the endway pressure, but also that of the upward pressure, is destroyed by progressive motion; and that the immersion, or draught of water, of floating bodies is susceptible of alteration, by being impelled at great velocities: this effect is

apparent when vessels are impelled at rapid rates by steam, and when the canal fly boats are towed swiftly along. The equilibrium of the vertical force, or upward pressure of the water on a floating body, is always disturbed by progressive motion: it no longer operates as being precisely equal to its weight, as it did when at rest, (see art. 3,) but by the motion is made to exceed it. The water operates with an upward impulse under the bottom, when a floating body is put in motion, which elevates, or causes it to rise up more or less in the fluid, and its displacement to be less than its weight: (see art. 12 and 19.) Thus, when floating bodies are put in motion by means of a horizontal force, and impelled with more than a certain velocity, they begin to rise up in the water, so as to diminish their area of resistance, and of course the degree of resistance. And when attaining to that certain velocity, if the speed is then expedited, the resistance will afterwards by no means increase as the square of the velocity according to theory, since, as the motion is quickened, so the area of resistance continues diminishing by the gradual rising of the body more and more out of the water, until in fact the moving power, and that perhaps without being so very considerably increased as might be expected, would give the body such a rate of velocity as to make it merely skim the surface, and cause the direct resistance from the water almost to vanish, and the theory to be no longer applicable. Indeed it is difficult to conceive but that there must be a terminal resistance at some certain speed after a floating body has attained that velocity at which it begins to rise in the water: (see art. 117.) At any rate, the theory is not applicable in all cases to floating bodies, nor can it by any means be considered to apply correctly in regard to bodies having supernatant parts. Or is it easy to conclude it free from error, even in respect to bodies when wholly immersed, and moving at different depths in water: for considering the rapidity acquired by some fishes, if the resistance actually increases with velocity so much as the theory states, it must at the rapidity at which they move be so intense as to render it almost impossible for their heads to sustain it, notwithstanding the repelling power fish are supposed to possess.

43.—From the immediately preceding observations, it cannot appear very likely that any law may ever be found out, that will apply correctly and generally to the resistance of water against floating bodies or ships of various forms, moving at different rates of velocities. And besides all this, there are other operations affecting the total resistance of a ship, as it relates to velocity, that tend no less to evince the intricacy and extreme difficulty of the case, as arising from the effects of the tenacity of water. If a power is required to be obtained by an impulsion against water, such for instance, that of the paddles of a steam ship, there must always be a body of water for them to operate against independent of that struck: for were the paddles to be moved in a narrow,

shallow, and confined space, or portion of water, although their area, or face, might strike the water with the same velocity, yet they would have less hold of it, for want of the cohesive attraction of a mass of water to operate on, and therefore they would acquire less force. The same feebleness of effect may be observed, when a waterman plies his oar in shoal water, although he dips it in as far. In respect to the paddles, their force against the water would be lessened in the proportion of three-sevenths (see art. 18,) if moved in a confined space and without the co-operation of the cohesive attraction of a surrounding mass. In the very same manner and in the like degree as the impulse is affected, the resistance to bodies moving through water is also affected by its tenacity: thus it happens that a ship is much easier moved along in a confined space, where she has just room enough to pass, than on an expanse of water: in the latter case, she has to contend with the tenacity of a mass surrounding her and to overcome it.

Hence, owing to the cohesive attraction amongst the particles of the mass surrounding her, a ship cannot, in moving forward, overcome the tenacity without disturbing and putting the water in motion all around her. The sensible deflection begins considerably beyond and before the bow, the water being there, in a measure, pushed forward by the force of the bow against it, in the effort of cleaving it; and as the tenacity pervades every part, so the water is deflected in all directions; for were the bow of a ship formed like a wedge, with the edge upright, the water would not be deflected in a lateral direction only, as might be supposed, but be deflected downward as well as sideways. Thus, by her motion, a ship pushes or drives a body of water before the bow and fore-body; and this impulse communicates a motion to the mass in the same direction, all along the sides of the midship part and under the bottom, and the water abaft is urged on after it. And, in short, a ship in motion *always carries with her an atmosphere of water.* This atmosphere accrues, not only from the impulse which the water receives by the ship pushing it forward in her efforts to pass through it, but also from the attraction and tenacity of the contiguous mass operating on the water adhering to her bottom; also, from the effect of the suction, as well as from the recoil produced by the friction. All these, as well as the onward impulse from the bow, tend to impart to the water, which is in close contact with the ship and to the mass immediately encircling her, a partial motion in the same direction with the motion of the ship.

44.—That portion of the water thus accompanying a ship, which is immediately next to her body, is not passed by so quickly as that at a little distance further off, and this latter not so quickly as that at a little further distance off, and so on gradually to where the water remains undisturbed by her motion: at which last distance, the water is passed by at the same velocity at which the ship moves forward. And, consequently, the velocity of a ship *through*

the water is actually always less than the velocity at which she moves forward. This would but be reasonable to conclude, even if facts did not prove it to be the case; of which, many could be adduced. As for instance, grass growing a little below the water, along the midship part of the bottom of a ship, is frequently observed to jut right out, and even to wave backward and forward as though she had no motion, when, at the same time, she may have been going perhaps three or four knots an hour. When, also, a ship is going fast through the water, if she then is suddenly stopped, the water that was accompanying her may be observed to continue the course she was taking, and to pass on a-head of her. A similar proof presents itself when a boat is rowed swiftly, at the interval of taking the beach, to land: the water which accompanied her in her course may be observed to follow immediately after her, and to come in as a wave upon the shore. Thus, also, when a ship comes into shoal water, that part of the water accompanying her which is under the flat of the bottom, is then found to be obstructed, or impeded in its motion, by passing over the ground, and its friction on the ground to check her head-way. It is known, from observation and experience, that small flat-built vessels, drawing only four and half feet of water, cannot go where the water is less than nine feet deep, without beginning to find considerable abatement to their speed from this cause; and their steering is also affected by it. The sailors term this effect, smelling the ground. It is further illustrated, by an instance relating to steam boats. The paddles used in propelling them move round to strike the water with very little more velocity than that at which the vessel goes forward, consequently, if the water did not in a measure accompany the vessel in her course, the paddles could not ply against it with much force; and it would be quite impossible for them to strike with such force as to be sufficient to propel the vessel forward at nearly the same velocity at which they move round to strike the water, since the water, supposing it did not accompany the vessel, must forsake, or recede from the paddles, nearly as fast as the paddles move to the water, and could strike it with but feeble effect, instead of plying against it with such great force as they must and are known to do.

45.—The total quantum of this atmosphere of water depends on the magnitude of the area of the midship bend, or bulk of water divided; and ships having the same area of midship bend, although the form of their fore bodies and after bodies may widely differ, yet, the bulk of the mass of water, thus accompanying a ship in her motion, will be the same; and it is probable the bulk of this carrying part of the water is always the same, let her be sailing at what rate of velocity she may. The quantum, or extent of it, as it respects particular parts around a ship must, however, (as will appear further on,) vary in accordance to the form of the immersed part of a ship's body, and according to the rate of the velocity at

which she may be sailing. It will also, at times, be of different extent on one side of a ship, to what it is on the opposite side. This latter will be the case when a ship is sailing close hauled to the wind, in consequence of the lee side being pressed more against the water by the lee-way, and less so on the windward side. As also whenever a ship heels, or inclines, there then being more water divided and displaced at the leeward side than at the windward side, the quantum of the carrying part of the water on each side will, from that circumstance, vary; and it may reasonably be inferred, that the forms of the curves, or arcs, displayed by the water immediately next the ship against the fluid contiguous to that water, and by the latter against the surrounding mass, may vary accordingly.

A sphere in motion is said to drag with it as much of the fluid as is equal to about six-tenths of the bulk of the sphere; and it is further assumed, that the fluid moves with, or accompanies the sphere, with the same velocity that the sphere moves at. This position, however, is extremely questionable, both in respect to the quantum as well as to the extent of the carrying part of the fluid, and also as it regards the velocity at which it is moved; at least so far as it may relate to the motion of a ship through the water. By making a computation of the bulk of that part of a ship's bottom which is under water, (or of her displacement,) in cubical feet, and also of the measurement of the surface of that part of the bottom in contact with the water, (or the measurement of the bottom from the water-line downward,) in superficial feet, it will be found, on an average of ships, that a quantum of water equal to six-tenths of the bulk of the immersed part of the bottom of a ship, would be equal to a portion of water twenty inches in thickness enveloping, or covering, every part of the surface of the immersed part of the bottom. This then would give an extent of only twenty inches, from the bottom at every part, for the channel of the carrying part, or atmosphere of water accompanying a ship in her motion; and this supposed to move with her at the same velocity at which she goes forward. But, certainly, as it relates to ships, the channel of the following water must be a great deal more extensive, and its velocity much less than this instance assumed of a sphere represents. No portion of this water can ever accompany a ship at the same celerity she moves at; no, not even that part of it immediately in contact with the bottom; for if it did there could be no friction exerted against the copper upon it, which, on the contrary, is found to wear away at every part by the friction of the water. Neither could the water have any force on the rudder to steer a ship, unless she had a motion through that water which is in immediate contact with the rudder. And in respect to other bodies moving in water, this is equally obvious. When fishes swim at a rapid rate, they impel themselves forward solely by the flexible action and muscular force of their tails against the water, similar in

operation to that of an oar in sculling a boat. At such times they may be observed to keep their fins in a position close to their bodies, so as not to obstruct their speed: a precaution that would be useless if the water in contact with their bodies accompanied them at the rate of their full speed. But they press their pectoral fins close to their sides to avoid any resistance from the water nearest in contact with their bodies, and only use them as a backwater to stop themselves suddenly when needful.

46.—It appears, therefore, as it relates to ships, that the atmosphere of water which accompanies them in their course, moves with them much slower than the speed they go forward at. This must also gradually vary according to the distance of the portions of the mass from her body: that part in contact with the bottom accompanies her the fastest in her motion; that further off gradually becomes slower with the distance, and so on till the water ceases to follow her at all. The channel, also, of the accompanying water must be much wider and more extensive than supposed: this is perceptible when a ship is sailing in shoal water, by the impediment to her speed occasioned by the obstruction which the water following her receives in passing over the ground. It is also apparent in the instance of steam boats, the paddles of which, often project a considerable distance beyond their sides: (see art. 44.) The extent of the mass, following a ship of three hundred tons burden, certainly cannot be less than five feet from her bottom on an average all round, or as taking one place with another; and is probably much more than that in extent only in a less sensible degree, water being very extensively susceptible of any disturbance.

But this atmosphere of water can never be of equal extent from every part round a ship in motion. Both its extent and also its form will be subject to variations; and this, not only when she heels and when sailing to windward as already pointed out, (see art. 45,) but it will also vary with the rate of her velocity. When a ship is moving slowly its expansion must then be wider beyond the sides, and its extent less beyond the after part of a ship than when she is going at greater speed. So also when she is going at greater velocity, it must extend less beyond the sides, and further beyond the after part of a ship than when she is moving slowly. It will likewise vary both in extent and form with the form of the bow: a sharp bow will cause a wider expansion of it in midships, and a less extension of it beyond the fore-body than a full bow; and on the contrary, a full bow will extend it further beyond the bow, and constrict its expanse in midships. And as the form and extension of this atmosphere of water is thus liable to variation, so the form of the curves, or arcs, displayed by the water immediately next the ship against the fluid contiguous to that water, and the latter against the mass surrounding it, as operating against the tenacity of the particles, may, (as before observed,) vary accordingly. (See art. 45.)

47.—The motion of this atmosphere of water, its various curving directions, and the friction among the particles of the mass, thus forced into action by the velocity of the ship, are, in their operations, blended with the total resistance of a ship by their effects as produced on the head-resistance, and on the suction, and on the friction. And although these three causes combined, may be said to constitute the total resistance to a ship, yet, the total resistance must, nevertheless, be considered as not wholly arising from the action of the body of the ship against the water, but as partly proceeding from the action of the water against itself. Thus, the bow, in its efforts to divide the water, in a measure drives it before it; and the water thus pushed, urges against and is opposed by that beyond it; and the resistance becomes partly that of the bow against the water that is struck by it, and partly that of the water struck against that of the contiguous mass. So also the whirling and multifarious curving directions imparted to the mass of water by the impulse given to it in following the ship, influences and varies the direction which the water would otherwise take in closing on the after-body, and thus affect the suction. And again, in consequence of a ship not actually passing through the water in contact so fast as she moves forward, the degree of friction on her bottom must become different to what it would be if otherwise.

48.—The total resistance of a ship is, therefore, rendered still more of a compound and diversified nature, by the circumstance of an atmosphere of water accompanying her when in motion. And which, consequently, adds to the other difficulties before enumerated (see art. 42,) attending the discovery of any general law, or rule, for ascertaining resistance, that would correctly apply to the varying forms of ships, and to their velocities as when impelled at different rates. And the improbability of any such law ever being found out must appear still more obvious from these additional circumstances. And as no law exists that can be depended on and resorted to by the practical shipbuilder, that can afford him much assistance in this highly important respect, a near calculation for practical purposes may prove of utility.

The following table (computed on an average of ships and diversity of curves,) is appended with this view: by the which, the total resistance to fast sailing ships in general may be readily and pretty nearly ascertained at any of the several rates of velocities they usually sail at. The first column in the table denotes the velocity of the ship, in nautical miles per hour; the second column, describes what the same velocity would be in feet and decimal parts of a foot per second; and the third column, shows the total resistance at that velocity, which one square foot of the area of resistance of the midship bend will meet with from the water, that is to say, how much in weight the resistance against one square foot will be equal or amount to. Then, by computing the whole number of the square feet that there are in the immersed part of the area of the

midship bend of any particular ship, in manner already pointed out, (see art. 13,) and multiplying such whole number of feet by the number of pounds weight of the resistance against one foot, as specified by the table against the particular velocity at which it may be required to be known, it will give the resistance against the whole number of feet in pounds avoirdupoise; or produce the total resistance in weight, which the ship will meet with when sailing at that particular velocity. The table extends to twelve miles per hour, few ships ever sailing faster than that: indeed it is conjectured by some, (though erroneously,) that fifteen miles per hour through the water is the utmost speed any ship can ever attain to.

Velocity in nautical miles per hour.		*Which are feet per second.*	*Resistance against one foot of the area of the midship bend in pounds weight avoirdupoise, at such velocity.*
Miles.		Feet.	Lbs.
3	equal to	5,07	10
4	,,	6,76	18
5	,,	8,45	28
6	,,	10,14	41
7	,,	11,83	55
8	,,	13,52	70
9	,,	15,21	87
10	,,	16,90	106
11	,,	18,59	124
12	,,	20,28	140

The resistance of water, as compared to the force of wind, has been ascertained to be in the following proportion: suppose in each case the surface to be a plane, and placed perpendicularly against the action of the fluids. Then, to give one square foot of surface a velocity through water, equal to the velocity at which the wind may blow, it would require a plane surface of 666 feet for the wind to operate upon, or blow against.

49.—The reader will perceive, from what has heretofore been adduced, the vast importance of lessening the resistance of a ship by every possible means, with a view to promote her velocity through the water; and this requires very studious attention, since every superfluous resistance increases fourfold with double velocity; and in consequence of the resistance increasing so prodigiously with increase of velocity, only a very trifling advantage in point of speed can, in comparison, ever be obtained by additional canvas on a ship. There are, however, indispensable properties, or qualities, in a ship, that require no less attention and regard than as relates to resistance. It would be fruitless to give to a ship a peculiar contour of body for sailing fast, unless that form would also enable her to carry

sufficient sail to force her through the water; and unless that form would also produce such proportions as would cause her to be a good sea-boat under canvas, and whenever contending with the raging elements. These are most essential properties, and require very deliberate consideration and circumspection in laying down a ship, in order that in their acquirement each of them may be nicely adjusted, not to predominate in the one, so as to be inadequate in another: for it so happens, as will hereafter appear, that what contributes to the attainment of one good property is prejudicial to the acquirement of some other. A ship cannot possess either of the essential good qualities in a perfect, or in the fullest degree, without prejudice to another quality, and, consequently, it is only to a certain degree in respect to either that she can acquire a proper portion of them all. This will evidently appear further on to be the case; and it will now be expedient to bring the different points, and what is connected with that part of the subject, under view. It may, however, be briefly remarked in this place, and it is much to be regretted that it should so happen, that in the giving to a ship such a form of body as will combine fast sailing with the possession of the essential good properties now about to be considered, lines of beauty cannot always be adopted; or, to be more explicit, a very superior ship in all and every of these respects, may not in truth be the most sightly, or handsome one. We proceed to treat next on those points by which the good properties of a ship are regulated and governed, and upon which they depend.

PART II.

SECTION I.

THE CENTRE OF GRAVITY OF A SHIP.

Description of, and its position.—From whence its force is derived and collected.—Its action and importance.—Considered a fixed point.—On what its height is dependent; and its situation fore and aft ways.—And comparative operation and effect from position.—Remarks on the ascertaining of its situation in a ship.

50.—The centre of gravity is the centre of the whole weight of the hull of a ship, and of what she contains, and of every thing appending to her. Thus, supposing a ship to be in sailing trim with all her sails set, if it were then possible to lift her out of the water, by a rope fastened at this centre, and to suspend her by it in the air, no part would preponderate; she would exactly poise, or balance, in every position. If held with her mast upward, the head would be no heavier than the stern, nor one side heavier than the other; the same if suspended with the bottom upward; and, if on her broadside, then the weight of the masts and upper part of her body would be exactly equal to, and poize that of the bottom part. It is that point about which all the parts do in every situation, or position, exactly equilibrate each other.

51.—The weight of the bulk of water displaced by a ship when at rest, being precisely equal to the weight of the ship and all she contains, she is pressed downward by a force exactly equal to this weight, in a perpendicular direction, tending to the centre of the earth; and she is also pushed in a perpendicular direction upward by the buoyancy of the water, with a force exactly equal to the same weight. The downward force of gravity, and the upward force of floatation are, when a ship is at rest, always precisely equal, and equally and directly opposed to each other.

52.—The mean directions of all the forces of gravity pass through the centre of gravity, since it is at this point where the weight of the whole ship is balanced; at which also the forces are concentrated, and from whence their action emanate. It is the centre of the downward pressure; and of the forces exerted wherewith, and the main-spring whereby, all parts of the ship are by its operation animated in the preserving an equilibrium, and in counteracting the efforts of any power to change her position in the water. It is the controlling centre; and upon its position depend some of the

most essential qualities of a ship; and although, perhaps, not at all times, strictly speaking, a fixed point in a ship, yet the centre of gravity may, for all practical purposes, be so considered: and it is the only fixed point in almost all ships to ground calculations upon. Yet, in assuming it in the following pages to be a fixed point in a ship, it will of course occur as still being subject to motion from the operations of wind and water upon her.

53.—The height of the centre of gravity is chiefly governed by the distribution of the weight on board a ship: the lower the weight is stowed, the lower also will be the centre of gravity; and when the weight is placed higher, the centre of gravity will be elevated accordingly. As, also, whenever there is more weight stowed abaft the midships than afore it, the centre of gravity will be abaft midships; and if a greater weight is placed afore the midships than abaft it, the centre of gravity will be afore the midships accordingly. In most ships, the centre of gravity is required to be below the surface of the water, in order to acquire from the weight on board a sufficient force to counteract any material power to overset them; this, however, is, in a measure, dependent on other circumstances to be hereafter explained. It may be sufficient, in this place, to remark in a general way, that the centre of gravity is required to be lower down in very sharp ships than in very flat ships; lower also in narrow, than in broader ones; and lower also in lofty, than in shallow-built ships. The higher the centre of gravity is elevated, the greater must be the breadth of the ship at the surface of the water, in proportion to the depth of her body under water. When the centre of gravity happens to be in the least above the surface of the water, the breadth of the ship at the surface of the water must then exceed double the depth of her body below water, or otherwise the ship will be liable to capsize, unless the body should chance to spread out, or to be wider above water, so as to receive and support her when she reclines on her side.

54.—If an exact model of a ship were to be made in proper proportion, as to size, scantling, and weight, the situation of the centre of gravity of the hull of the ship, without any thing on board, might then be nearly ascertained by suspending the model by a string, and finding out the point at where it would in every position poize, or hang evenly balanced. Or, it might be ascertained on the draught of the ship, by laying down in the first place a number of level lines to divide the ship into different horizontal sections; and computing the weight between each section of the materials of which she is built; then the height at where there is as much weight above as below, would shew the *height* of this centre. In the second place, by laying down a number of lines (similar to those of the frames of a ship,) to divide her into different perpendicular sections, and computing the weight between each section, of the materials of which she is built, the spot where there is as much

weight afore it as abaft it, would show the situation of this centre *fore and aft-ways*. Then, where the height horizontally intersects the perpendicular situation fore and aft-ways, at an equal distance from the sides, that spot would be the position of the centre of gravity of the hull of a ship, without any thing on board or appending to her.

But it is rather difficult to ascertain by computation, the situation of the centre of gravity of a ship, when she is equipped for sea, owing to the multifarious description of articles that comprise the weight of what she has on board; the difference in their specific weights, and the manner in which they are usually intermingled by stowage; to say nothing of the complexity in regard to her masts, rigging, and sails. These circumstances render such calculations both tedious and intricate; neither can they at the best be depended on for accuracy; nor, when made, be of permanent utility, since the disposition and quantum in weight on board a ship is continually altering. Therefore, trial, observation, and experience in the distributing of, or stowing the weight on board, are found after all to be the best guides, with a view to bringing and keeping the centre of gravity to its proper height and position.

SECTION II.

THE PLANE OF FLOATATION

Described.—Its form subject to variations.—Of great consequence in making computations.—Its expanse also liable to variation.—The form of it of much importance.—Care required in laying it down.—And the best form pointed out.

55.—The plane of floatation is represented by the line described by the surface of the water round the ship; either when she is upright, or when inclined, or when in any other position deviating from the equlibrium. Hence, the form and situation of the line so described becomes subject to changes by the motion of a ship; while, notwithstanding any changes in the position of a ship, resulting from her motion, the surface-level of the water remains unaltered. And as the centre of gravity may be considered a fixed point in a ship, so the surface of the water may be deemed an unaltering line of level. And it is that point, and this line, that afford the only steadfast guides to found calculations upon, as relating to most of the essential properties of a ship. Owing to the variation in the form of the plane of floatation by the motion of a ship as before mentioned, there arises a deviation in its extent, or spread, at different parts. When a ship heels under canvas, the spread is usually expanded at the lee side, (the one she leans on,) and contracted on the weather (or opposite) side. As, also, when the bow happens to be depressed in the water by the force of the

wind on the sails, and the stern elevated, it usually spreads more forward and less aft. So that both the form and expanse of the plane of floatation are liable to much diversity from these, as well as from other adventitious causes.

56.—As it is at the surface of the water, where the downward force of the gravity of a ship, and the upward force of her buoyancy, meet, so, upon this surface, all her motions are suspended, and upon it hinge her movements every way. The plane of floatation being also the plane of her support from the water, as well as the seat of her motion, its form and extent becomes a matter of vast importance, and requires much circumspection in designing the draught of a ship. The form of the intended line of floatation, or of the water-line described by a ship, when down to her proper bearings, and in sailing trim, and in an upright position, that is to say, the plane of floatation when she is in equilibrium, claims much attention from the draughtsman. It should present an extended line of bearing, or have a long continuation of good breadth in a fair gently curving line from the midship part toward the bow and quarter, in order to afford to the ship in all her motions as spacious and as effective a support as possible.

SECTION III.

THE CENTRE OF DISPLACEMENT.

Observations.—Other names given to this centre.—Description of, and situation.—It is a shifting centre; and why so.—Its position with the centre of gravity explained.—Their co-operative effect in keeping a ship upright.—And conflicting operation in the oversetting her.—Observation as to the comparative height of these two centres.—And their operation illustrated as it respects the position of a ship fore and aft-ways.

It has been observed in another place, (see art. 3,) that a ship *when at rest*, is always supported, or pressed upward by the buoyancy of the water, with a force precisely equal to her weight, or natural tendency to the centre of the earth; and that the weight of the bulk of water she displaces is exactly equal to her own weight. With a view to elucidation, it will be expedient in this section, as well as in some of the following ones, to consider the displacement of a ship as being always precisely equal to her weight, without noticing or having the least reference to any variation that might by possibility happen in the displacement of a ship, by any partial rising in the water, as resulting from her velocity (see articles 12, 19, 42, and 117.)

57.—The centre of displacement goes under various denominations, such as the centre of magnitude of the immersed part of a ship; the centre of cavity; the centre of floatation; the centre of

buoyancy; the centre of capacity; the centre of gravity of that part of the ship's body which is immersed; and the centre of support, or of the vertical force exerted by the water in supporting the ship. It may be explained as the centre of the upward force of buoyancy, as opposed to the downward pressure of gravity. Or, as that point (whether such point be afore or abaft dead flat,) from whence there is precisely as much water displaced afore it, as abaft it; above it, as below it; and as much on one side of it as on the other. It may also be defined, as the centre of the hollow, or of that part of the ship's bottom which is under water; and of course this centre must, therefore, be situated below the surface of the water. And as both sides of a ship are supposed to be precisely alike, this centre, when a ship is upright, must also be in a perpendicular with the middle line of the ship fore and aft-ways. Was the bottom of a vessel to be quite flat, and the sides from the bulge upward perpendicular, this centre would then be equidistant from, or midway between, the plane of floatation and the lower part of the bottom. Hence, it will be nearer the surface of the water, when ships are built narrow and flat, than when constructed deep and sharp; and whatever form the section of the timber in the midships may be of, it will always be situated near, the centre of the immersed part of its area.

58.—The centre of displacement becomes a shifting point whenever the equilibrium of a ship happens to be disturbed. It is continually changing its place when a ship is under sail: its situation alters by the heeling of the ship, since, when she inclines, a larger bulk of water is then displaced at one side of the ship than at the other side. That side upon which she reclines being forced deeper in the water, it will occupy a larger space in it; and the opposite side being uplifted from it, will occupy exactly so much less space in the water. And, consequently, the centre of the bulk of water displaced will always shift as the bulk of it shifts; or, the centre will verge toward that side of the ship which occupies the largest space in the water.

59.—When a ship is in a state of equilibrium, or perfectly upright and at rest, the centre of displacement and the centre of gravity are then situated perpendicularly one with the other, and are both also posited in a perpendicular with the middle line of the ship as drawn from forward to aft; the centre of displacement is then at an equal distance from each side of the ship; the centre of gravity is so also; and the only difference in the position of these two centres will then be that one may happen to be higher than the other. But whenever a ship inclines on one side, a change immediately transpires; the centre of displacement then shifts over toward the lee side, or to the side she reclines upon; and the centre of gravity being a fixed point in the ship, and not altered by the heeling, the two centres do not then remain in a perpendicular direction to one another. If, when the ship is inclined, the centre

of gravity is (as it should be,) to windward of a perpendicular line as drawn up from the centre of displacement, when so inclined, the force at both centres will be exerted, and will co-operate to bring the ship upright; the greater buoyancy being to leeward of the centre of gravity, will force the lee side up; and the greater weight being to windward of the centre of displacement will press the weather side down. And these two forces as thus exerted and so co-operating, act together in direct opposition to the power that inclines the ship. And the further the centre of displacement happens to be to leeward of the centre of gravity, or, the wider the two centres are then horizontally separated apart, the greater will be their united forces to restore the equilibrium: precisely corresponding with the law of the lever, imagining the power that heels the ship to be at the end of the handle; the prop to support the pressure, to rest on the centre of buoyancy, or of displacement; and the point of the lever, to be under the centre of gravity prizing that up. But should it happen from any cause, when a ship leans over, that the centre of gravity falls to leeward of the centre of displacement, (or, supposing a perpendicular line to be drawn up from the centre of displacement when a ship is so inclined, and that the centre of gravity becomes to leeward of this line,) the centre of gravity would then press down the lee side, and co-operate with the power that inclines the ship, and lay her on her beam ends, or she might even be turned topsyturvy: and to continue the comparison of the lever, the weight then would get between the handle and the prop, and bear down the handle.

60.—These effects will be governed by the form of a ship's body, (see art. 94,) and will also be dependant upon the height of the centre of gravity: (see art. 95.) It is, however, by no means indispensable, that the centre of gravity should be lower down, or be near so low, as the centre of displacement. It might even be situated as high as the plane of floatation; or even higher than that, since, if the form of body prevented the centre of gravity from getting perpendicularly to leeward of the centre of displacement when the ship heels, or if there was a greater breadth, or spread out in the body of the ship above the water-line, to afford sufficient additional buoyancy to leeward, to bear her up and support her at the lee side when leaning on it, she would not upset.

61.—When a ship is in a state of equilibrium, the centre of displacement is neither afore nor abaft the centre of gravity, but both centres are then in a perpendicular direction with one another. But if from any external power, or extraneous cause, such as from the force of the wind on her sails, the bow should be pressed deeper in the water, and the stern elevated, the fore-body would, in such case, displace more water than before, and the after-body as much less; and, consequently, the centre of displacement would be shifted further forward, and not remain perpendicular with the centre of gravity, as it was when the ship was in a state of equi-

librio. And just so if the after-body was forced deeper in the water, and the bow uplifted, the centre of displacement would verge further aft than before. And, in these cases, the forces exerted at the centre of gravity and at the centre of displacement, combine in their efforts to restore the ship to a state of equilibrium, in opposition to the power that deranged it; and this in the identical manner as before exemplified in their operation in rightening a ship, when by any power she is heeled on one side.

SECTION IV.

THE META CENTRE.

Its position defined, and what it describes.—It is a shifting centre.—And even not always in existance.—What it evinces when it is above the centre of gravity; and, also, when below it.—Its position as it relates to the form of the body of a ship.—Another mode of ascertaining such particulars pointed out.

62.—The meta centre (as it is commonly taken,) is that point, where a line drawn up perpendicularly from the centre of displacement at the time a ship heels, or when she is inclined on her side, cuts a line that was drawn perpendicularly with the centre of gravity at the time when she was upright. Consequently it exhibits the position of the centre of gravity with that of the centre of displacement at the time of a ship being inclined; and whereby the degree of their co-operative force in resisting any power to heel the ship, may, by their relative positions, be perceived and calculated upon. It may, however, be taken in a more extended sense, the meta centre might be understood to relate to the motion of a ship fore and aft-ways, as well as to the athwartship way; to the temporary depression either of the bow or of the stern, as well as to the heeling on either side; and, in such view, its station on a perpendicular line drawn from the centre of gravity when the ship is in equilibrium, will depend upon the position of the centre of displacement at any time when the ship is not in a state of equilibrium. The meta centre is a shifting centre; its distance from the centre of gravity is perpetually fluctuating up or down by the shifting of the centre of displacement as produced by the various movements of the ship; and as the centre of gravity and the centre of displacement are, when a ship is in a state of equilibrium, perpendicular to each other, therefore, no meta centre can then exist; and, consequently, it is only when the ship changes from such position that this centre is produced, or can be made to appear.

This centre is, however, usually understood as particularly relating to the sideway motions of a ship, or to her heeling; and in such respect it will be proper to proceed in explaining it. Its position is always on the line that is drawn perpendicular through

the centre of gravity at the time the vessel is upright. When, therefore, a ship is inclined, and the meta centre is found to be higher up on this line than the centre of gravity, it proves that the centre of gravity is to windward of the perpendicular from the centre of displacement; and when the meta centre is lower down on this line than the centre of gravity, it shows that the centre of gravity is to leeward of the perpendicular from the centre of displacement, since, if a perpendicular is drawn up from the centre of displacement when a ship is inclined, and it cuts the beforementioned line below the centre of gravity, the centre of gravity will evidently show itself to be to leeward of the perpendicular drawn up from the centre of displacement.

63.—When the meta centre is above the centre of gravity, the centre of gravity being then to windward of the centre of displacement, the forces at the centres of gravity and of displacement cooperate to bring the ship upright, or to resist the power that heels her. But when the meta centre is below the centre of gravity, the centre of gravity in such case being to leeward of the centre of displacement, the force of the centre of gravity no longer resists, but then unites with the power that inclines the ship, and she must inevitably go on her beam ends, and perhaps capsize. This ever must occur, whenever, conjointly, the centre of gravity happens to be above the plane of floatation, and the form of the midship bend below water happens to be quite circular, or to describe half of a circle, since such circular form of body admits of no difference in the displacement of the two sides when a ship inclines; and in consequence of the centre of displacement not altering its situation in the ship when heeling, the centre of gravity would lean to leeward of it, or the meta centre would be below the centre of gravity. Hence, whenever the centre of gravity is required to be above the plane of floatation, the midship bend, in order to avoid this danger, should on no account be thus circular; but, on the contrary, be so formed, that when the ship inclines, the centre of displacement may always shift to leeward, sufficiently to bring the meta centre above centre of gravity: (see art. 65.)

64.—The position of the centre of gravity with that of the centre of displacement, as it relates to their respective force and effect, may be exhibited by another mode, namely, by drawing on the plane of floatation one line from each centre exactly perpendicular, at the time when the ship is in the inclined position, and then, whichever of the two centres may prove either to leeward or to windward of the other, and how much so, will be seen by observing where the perpendicular lines intersect the surface-level, or cut the plane of floatation; and their distance apart will thus be made to appear on a level when the ship is in the inclined position. And as the upward force of buoyancy, and the downward force of gravity, are both exerted *perpendicularly*, by thus displaying the distance of the two centres apart on a *level*, their effects may be more

readily seen, and their forces better calculated upon, than from the position of the meta centre.

SECTION V.

THE CENTRE OF MOTION

As it relates to a ship. Its position in a floating body defined.—Upon what its situation in a ship depends when she heels.—And where then situated. And, also, as in respect to the pitching motion.—Is a moveable, or an imaginative point.—Its position with the centre of gravity considered.—Remarks on this centre.

65.—The centre of motion is not to be conceived as a point in a ship without motion, since every part of her is subject to motion in a greater or lesser degree, either from the undulations of the waves or from the carrying of sail; and under no such operations will her motion ever describe a fixed point or centre. It should rather be understood, as that point which remains most at rest, whilst other parts surrounding it are in greater motion. But with a view to form a clear idea of the nature of this centre, as it relates to the rolling motion of a ship, imagine a body in the form of a cask floating on its bilge, or side, the bilge to be perfectly round, or to form a circle, and to be in substance of equal thickness and weight at every part; and imagine it, also, by its own weight alone to sink down to the centre of the circle, or to swim with exactly one half of the body in the water, and invariably to do so, however the body might be inclined, or even if it was turned round, that the middle of the body would in such case always continue level with the surface of the water. The centre of this body would of course be equidistant from its ends; it would also be equidistant from the sides, or exactly in the middle of the circle. And the centre in consequence of continuing always precisely at the surface must remain without the least motion, while the body is turning round in the water, or whenever inclining. This is, therefore, the centre that is meant by the centre of motion.

The centre of gravity of this body will be in the centre of the circle also, since the centre of the whole weight of the body resides there; and, therefore, the centre of motion and the centre of gravity would, in such a formed body, and under such circumstances, be precisely situated at the same point. As this body athwartship-ways is perfectly circular, and revolves in the water with its centre constantly at the surface, the centre of displacement must always preserve exactly the same distance from the surface of the water, while the body is moving round; and the shifting of the centre of displacement during the rotary motion would describe a circle, whose centre would be the centre of motion ever situated on the plane of floatation, and always remaining directly perpen-

dicular over the centre of displacement whilst the body is turning round. The form of the transverse section of this body being that of a perfect circle, there must always be as much water displaced by it on one side of the centre of gravity as on the other side of it, and, therefore, the centre of displacement would invariably keep perpendicular under the centre of gravity whenever the body inclined; and these two centres being always so posited, there, consequently, could never be any meta centre.

66.—It will be readily seen from the preceding illustration what is to be understood by a centre of motion. The form of a ship, however, will not admit of its being so minutely defined: the situation of this point in a ship, must ever depend upon the position of the centre of displacement, and also upon the situation on the ship at the same time of the line formed by the surface of the water round her, (or of the plane of actual floatation;) and as that centre and this line are both perpetually changing with every motion of a ship, the centre of motion must, of consequence, be considered a moving, or an imaginary, point. Thus, as soon as a ship begins to heel, the motion on this centre commences at the surface of the water, at a point in the middle line of the ship, this point being, while she is upright, in a perpendicular both with the centre of displacement and with the centre of gravity; when she heels further over, the motion then centres more toward the side on which she inclines, the centre of motion gliding gradually on the surface while, and as, a ship inclines, following the shifting of the centre of displacement, and ever keeping perpendicularly over it: a kind of double motion being thus produced that is very common in nature to moving bodies, when subject to the operation of conflicting forces.

The height of this centre is invariably at the plane of floatation, or it keeps constantly on a level with the surface of the water, while and as a ship inclines; for as the buoyancy of a ship is determined at, and governed by, the surface of the water, therefore, any variation in her position must consequently hinge at the surface: (see art. 56 and 70.) The centre of motion in a ship, when she heels is, therefore, that point where a perpendicular, drawn up from the centre of displacement at the time when she is inclined, intersects the plane of actual floatation, or a line that happens to be level with the surface of the water, at the time she is so inclined; and it is at this point where the pressure is centrically sustained, and also where the support afforded by buoyancy is centrically operated upon, by the power that inclines the ship, in opposition to the force of the centre of gravity in striving to keep her upright.

67.—But the centre of motion not only relates to the heeling and to the rolling motion, but also to the pitching motion of a ship, as well as to that arising from the force of the wind on her sails when they depress the bow in the water, and simultaneously lift the stern. The centre of motion then gradually verges a little more forward by

the plunging, or depression of the bow, or glides a little more aft, when the stern dips, ever following the shifting forward or aft of the centre of displacement in such cases, and invariably keeping perpendicularly over the centre of displacement, and on a level with the surface of the water, as before exemplified in respect to the heeling and rolling motions of the ship.

68.—Hence, the centre of motion, as a moveable, or imaginative point, glides both athwartship-ways, and fore and aft-ways from the perpendicular with the centre of gravity, constantly keeping level with the surface of the water; and, notwithstanding, the position of a ship while she is inclining, or when she is rolling or pitching, incessantly changes the situation of the line described by the surface of the water at her sides and extremities, by being at times higher on one side of a ship, while lower at the opposite side; higher also forward, while lower abaft, than the line as described around her when in a state of equilibrium; yet, the centre of motion always continues on the plane of floatation, or keeps on a level with the surface of the water during every change, and in all the various positions of a ship; and this ever will be the case, whether the centre of gravity happens to be situated at either above or below the water-line described around the ship when in a state of equilibrium.

69.—The centre of motion and the centre of gravity may chance to be at the same point when a ship is upright, (which is the case when the centre of gravity is then level with the surface of the water;) but, notwithstanding this, the moment she begins to incline, the centre of motion will begin to shift as before described, and the points to be separated. Hence, the centre of gravity ought never to be confounded with, or be considered as identical with the centre of motion; they are, in fact, quite distinct: the centre of gravity is a fixed point in a ship; and the situation of the centre of motion in a ship, is entirely dependant on the operation of the buoyancy of the water on her while she is in motion. The centre of gravity, though a fixed point in a ship, is uplifted by the heeling of the ship, while the centre of motion invariably keeps at the same height of level during the inclination. It is only to imagine the beam of a pair of scales, and to suppose the centre of gravity to be at one end of the beam; the power that inclines the ship to be at the other end; and the centre of motion to be midway, at the pivot, supported at the surface of the water by a prop from the centre of displacement; and a familiar idea may then be entertained of the operation. Either end of the beam may go up or down, but the middle remains stationary. The only difference in the comparison is, that the centre of motion in a ship, glides a little in a level direction, or gradually deviates its situation on the surface-level, as the position of the ship varies; a sort of eccentric movement takes place, in consequence of the power that heels the ship, and the force that resists such power, being both of them

under the obeyance of the fluid that supports her. The centre of motion emanates, or owes its origin, entirely to the conflicting efforts between the power exerted to incline the ship, and the force at the centre of gravity to keep her upright; that is to say, in their operations of pressure on the centre of buoyancy, (or displacement;) the centre of motion, in following over the centre of displacement, always shifting precisely as much as proves requisite for the conflicting efforts just mentioned to be evenly poised at its situation on the plane of floatation: or, it becomes the centre of balance between the power and the force, as sustained on the surface of the water at the point of buoyancy, or of support. The centre of gravity is moved up; the point where the movement centres is the centre of motion; and although the centre of motion, while gliding and playing round the centre of gravity as its controlling centre, may, by its shifting sideways have as much motion as the centre of gravity may have in being uplifted; yet the point at where the power and the force are poised, and upon which they hinge and move, must be deemed the centre of motion.

SECTION VI.

THE AXIS OF INCLINATION.

Its different appellations.—Description of.—Its situation in a ship.—Its position.—Its height.—Is a vacillating axis.—How operated upon; and in different degrees.—The same points considered as relating to the pitching motion on the transverse axis.

70.—This axis is also called the axis of oscillation, and also the longitudinal axis. It is an imaginary line, passing horizontally from head to stern, on which a ship may be supposed to oscillate, or turn while rolling, and incline when heeling or listing; and should be conceived as purely metaphysical. The surface of the water upon which a ship is seated, may be considered a fixed plane. It is here, at where the upward force of buoyancy and the downward force of gravity precisely meet, both when a ship is in an upright position, as well as when she is reclined. And it is also on this plane, where, when a ship is inclined, the downward force at the centre of gravity, and the upward force at the centre of displacement, (or at the centre of buoyancy,) always operate and exert their efforts in preserving the equilibrium; and this in the degree according to the horizontal distance apart of their respective positions. The plane of floatation is also the seat of the ship's motion; since, when she is leaning over, while that part of her body which is contiguous to the surface is moving one side further in the water, and the opposite side more out of it, the water itself remains level and stationary. And as the centre of displacement ever precisely preserves its just distance from the surface of the

water during the time a ship is inclining, and such inclination being defined, guided, and governed, entirely at the surface, by the buoyancy of the water, the motion of a ship, while reclining, must, consequently, always hinge, or centre, at the surface of the water, however the centre of gravity may be situated, since the position of the centre of gravity, can in no case or degree prevent the regular operation of buoyancy, when any power inclines a ship.

With a view to elucidation : suppose the centre of gravity of a ship was placed at the upper deck, and that she was kept upright by guys, or ropes, from her masts; and these ropes being let go, she was to capsize; it would be impossible for the ship, in the act of oversetting, to revolve on her centre of gravity, since that centre would be in the air; but quite the reverse must happen : her bottom would commence turning in the water, and then her topside, and last her deck would turn in the water, till she came bottom up; and the quantum of water displaced, continuing in meanwhile the same, the centre of displacement would ever keep at its just distance from the surface of the water, and, consequently, the motion would centre at the surface; or, the centre of gravity would turn on the axis of inclination, ever situated (as will presently appear,) at the surface, and always passing through the centre of motion. The same would happen if the ship was placed bottom up, and the centre of gravity was to be at the keel; and however the centre of gravity may be situated, the centre of motion will, in all cases, constantly reside at the surface of the water. The height of the axis of inclination keeps always on a level with the surface of the water, and it extends fore and aft in a line parallel to the horizon. When a ship inclines, some part of her body above water descends on the lee side, and an equal part under water ascends on the weather side; and the part about midway, where the body had neither descended nor ascended, but preserved the same height of level as before, is the situation of the axis of inclination, or of that on which she reclines. And the motion of a ship, while heeling, and when rolling, always hinges in this manner at the surface of the water.

71.—Hence, as briefly noticed before, the axis of inclination must ever pass through the centre of motion; it must also with it always keep perpendicular over the centre of displacement while a ship is heeling; and follow and accompany the shifting of the centre of displacement, in like manner with the centre of motion : (see art. 66.) Consequently, the axis of inclination is a vacillating and imaginary axis, and ought never to be conceived as an axis invariably passing through the fixed point of the centre of gravity of a ship, since that can only happen transiently, when the centre of motion chances to glide to, or touch the same point at which the centre of gravity is situated. A ship floating in water becomes subject to the laws of that fluid; and all her motions in the water must ever hinge, or centre, at the surface, let the situation of the

centre of gravity be where it may. It is very different as regards a ship, and as it respects a body in motion out of water, since the latter has nothing to interfere with, or to hinder the mean direction of the forces from passing through and operating at the centre of gravity; but a ship acquires, by her floating in water, a centre of gravity peculiar to floating bodies, and may be considered as having two centres of gravity; the one of the weight of the ship, (usually denominated the centre of gravity,) and the other, the centre of gravity of the bulk of water she displaces, (or the centre of displacement.) These two centres are rarely situated at the same point; and if, when a ship is upright, they should happen to meet, they separate the instant she begins to incline, the centre of gravity being a fixed point in a ship, to control, and the centre of displacement, the shifting centre to guide the motion of inclination evenly on the surface of the water upon the point of support situated at the surface.

When the pressure of the wind on the sails recline a ship, the mast may be considered as a lever communicating a power in opposition to the force of the centre of gravity; and the prop, or fulcrum, upon which this lever presses, may be considered as the point of support at the surface of the water, situated at the centre of motion, perpendicularly over the centre of displacement. When the ship is inclined, the centre of gravity and the centre of displacement being then separated wider apart, the power that heels her is opposed at the weather side by the force of gravity, because the weather side being elevated from the water by the inclination of the ship, the bulk of water displaced to windward becomes smaller than it was before, while the weight on that side remains the same; hence, the weight of the water, displaced at the weather side, becomes less than the weight that is in the ship on that side; and the weight on board tends to press the weather side down, and which side becomes liable to yield to the downward pressure, in consequence of having lost part of its support from the water. On the other hand, the power is opposed on the lee side by the force of buoyancy; the lee side being immersed lower in the water by the heeling of the ship, the bulk of water displaced by her to leeward becomes larger than before, while the weight that is in her on that side remains the same: hence, the weight of the water displaced at the lee side, becomes greater than the weight on board at that side; and the buoyancy of this larger bulk of water tends to force or press up the lee side, and which side becomes liable to yield to the upward pressure, in consequence of the weight being inadequate to the keeping it down. In this manner, the forces exerted at the centre of gravity, and at the centre of displacement, combine their efforts to oppose the power that inclines the ship, and when she comes down to her bearings, and will heel no further under her canvas; then these forces and this power become equably opposed to each other; and their conflicting efforts are evenly poised, or balanced,

at the axis of inclination, ever passing through the point of support, and the centre of motion at the surface of the water.

A power passing athwartship-ways to the axis of inclination, if kept in a level direction, or placed even with the surface of the water, could never heel a ship, nor produce any other than a horizontal-sideway motion; but if the power was to be shifted, and to be applied above the surface of the water, it would then tend to heel the ship. Thus, the power exerted by the pressure of the wind on the lower sails of a ship will heel her less than that on the topsails; and the latter, less than that on her topgallant sails, supposing there to be an equal spread of canvas in each case. Hence, the higher a power is applied above the axis of inclination to heel a ship, the stronger will be its effect.

72.—There is not only the axis upon which a ship may be supposed to oscillate sideways, or to move on when she rolls or inclines, but there is also another axis upon which hinges her motion fore and aft-ways, as when she is pitching; or when, from the force of the wind on her sails, her bow is depressed in the water and her stern raised. This is called the transverse axis, and, like the other, may be conceived purely metaphysical. The transverse axis passes right athwart, or across, the ship in midships, and keeps parallel with the surface of the water, and always at the same height with its surface. It passes through the centre of motion; and moves with it in its shifting either a little more forward or a little more aft, constantly following the shifting of the centre of displacement, and ever keeping perpendicularly over it. And upon this axis the centre of gravity and the centre of displacement operate to counteract the pitching motion, and to preserve the equilibrium in an horizontal position, in the same manner as they operate in respect to the rolling motion, in the keeping a ship upright.

SECTION VII.

THE AXIS OF ROTATION.

Otherwise called.—Described as in a floating body without progressive motion.—And suchwise in a ship.—Its station but little influenced by the centre of gravity.—Its situation in a ship athwartship-ways: and, also, as to its being forward or aft from midships, explained.—Is perpetually changing these situations.—On what its station depends, and how varied; as in respect to the form of the ship; her difference of draft of water; the action of the rudder; and from a variety of circumstances when a ship is under sail.—Its situation can be defined only transitorily.—How operated upon by the rudder; and also by the sails of a ship.

73.—This is likewise termed the vertical axis; and also the axis

of a ship's tacking; and is purely of an ideal description. It is an imaginary perpendicular axis, situated somewhere in the midships, by which a ship may be supposed to turn about in steering. The action of the water against the rudder, when the helm is put over, gives to the ship a rotary motion; her head moving one way, and her stern the opposite way; while somewhere in the midships no motion of the kind exists: just as though a ship was suspended there on a pivot and traversed upon it.

In order to explain clearly in what manner the precise situation of an axis of rotation might be ascertained, it will be expedient to advert to an example of a floating body uninfluenced by the various motions, attitudes, and incidents, to which a ship is subject. Imagine, therefore, an oblong floating body of the proportionate dimensions of a ship, and the under part of the bottom of this body to be perfectly flat; and from the bilge upward, its sides to be upright all fore and aft; and further, that its fore-body and after-body tapered sideways to a point; that they were also formed exactly alike, and were equally immersed, or that the body drew the same water forward as aft. In such a body as this, the centre of displacement would, of course, be equidistant from the ends, and also be equidistant from its sides, and at halfway between the surface of the water and the under part of the bottom. The centre of gravity would be perpendicular with the centre of displacement. And the centre of motion, residing at the surface of the water, would also be in the same perpendicular. If when this body is quite upright, and without progressive motion, a power was to be applied in midships to twirl, or turn it round, horizontally, as a ship moves in tacking about, the power would operate by pushing the water from one side of the fore-body, in one direction, and by shoving it from the opposite side of the after-body in the contrary direction. And the fore-body and after-body being exactly alike, the lateral resistance of the water against the fore-body, would be precisely equal to that against the after-body; consequently, the resistance being equal, so the distance that each end would move in turning about, would be equal also. Hence, the rotary motion must centre equidistant from the ends, and at halfway between the sides, and there assume a vertical axis, from which the body traversed, that axis passing, in the instance before us, perpendicularly through the centre of motion, the centre of gravity, and the centre of displacement. This then is the axis that would be the axis of rotation of a body of such a form, and under such circumstances.

The centre of gravity of a ship might be supposed to have some influence on the situation of the axis of rotation, because of the forces exerted on a body naturally tending to pass through that centre, when such body is moving in an unresisting medium; but the axis of rotation in a ship can never be but very slightly, if at all, influenced by the centre of gravity. The situation of the axis

of rotation in a ship being almost wholly governed by the lateral resistance of the water. By way of illustration: suppose a ship in an upright position, to be placed with her broadside against a strong current; and to be held there by a rope fastened to such a spot or point in midships, at the which it would exactly balance the force of the stream against the fore-body, and that against the after-body, so as to keep her steadily athwart it, without the aid of guys from forward or aft. It would little matter, where the centre of gravity was; the point at where the rope was fastened would be at the axis of rotation, and perpendicular to the centre of the lateral resistance of the ship, as without progressive motion. And being evenly poised in this situation, either her head or her stern might be moved up or down the stream with facility, while the point where the rope is fixed would remain stationary. By the foregoing illustration, the nature of the axis of rotation will appear obvious: it is, however, extremely difficult to define its precise situation in a ship when under sail, as will presently appear.

74.—When a ship is in motion, and the axis of rotation happens to be situated much abaft the centre of gravity, the latter might possibly be supposed to have some effect in approximating the former toward it; but in regard to any such effect, it should be remembered, that the weight of the ship is entirely borne by the water; and that in whatever degree the centre of gravity could, under such circumstances, operate, it could only act, in this respect, horizontally; and that, in operating in this direction, it would have to contend against the equalization of the lateral resistance of the water. Its effect cannot, therefore, but very triflingly influence, if it at all affects the situation forward or aft of the axis of rotation; and for any practical views, this axis may be considered as being situated at the spot where the resistance of the water against the fore-body, in being turned one way, and the resistance against the after-body, in being turned the reverse way, may, at any juncture, happen to balance, or to be equalized.

The station of the axis of rotation in an athwartship direction, will depend on how much the ship heels. When she is upright, it will of course be in midships; but when inclined, it will then be toward the side upon which the ship reclines: *it will invariably accompany and pass through the axis of inclination.* However much the ship may heel, it will, on being acted upon, ever operate in a perpendicular direction; and in preserving the perpendicularity, will of course vary its position vertically in the ship as she heels. The axis of rotation will gradually shift its place athwartship-ways, as, and while a ship is coming about, in the following manner. Suppose the ship to be heeling under sail, and going to tack; the rotary motion will commence, as though she was turning on a pivot contiguous to her lee bilge; then, when the sails are shaking in the wind, and the ship becomes upright, the motion will centre at the middle line of the ship; and, lastly, when the sails fill again,

and she is heeling down on the opposite side, the motion will centre toward that side. And, in this manner, the axis of rotation will constantly shift and accompany the axis of inclination, as, and while the ship is coming about; and in the being acted on, will operate in a perpendicular direction. The axis of rotation will invariably assume a direction, that is perpendicular to the surface of the water, while it is shifting toward either side of a ship: each side of the ship describes the same rotary arcs, or participates in the same manner of the motion only while she is upright, since, when she heels, the axis of rotation gets to leeward of the middle line of the ship.

75.—The axis of rotation, in its shifting the fore and aft-ways, to where the lateral resistance may happen to be centrically balanced, will always keep in the line of, or on the axis of inclination, and ever pass perpendicularly through that axis. It will not be confined by the centre of displacement, nor by the centre of gravity, in its freely shifting the fore and aft-ways to the centre of lateral resistance, though, in so shifting, it will often transiently touch the identical points of the centre of displacement and of the centre of motion, and then transiently connect itself also with the meta centre. But though the station of the axis of rotation in the fore and aft direction, is dependant on the situation of the centre of lateral resistance, yet the centre of lateral resistance will seldom be at the same point as where the centre of the surface that is presented laterally by a ship to the water may happen to be situated, since that will be governed by a variety of circumstances. As, for instance, it will be dependant on the form of a ship: if her body below water is very full forward, and very lean abaft, the centre of lateral resistance will be abaft the centre of lateral surface, because the surface of the fore-body will then laterally oppose the water more obliquely than the surface of the after-body will do. The lateral resistance, either forward or aft, will ever vary with the degree of the obliquity of the surface, which it presents to the water; or, it will be according to, or as the surface may happen to be more or less tapering, as well as more or less upright. And hence, the lateral resistance to the after-body, is commonly stronger than that against the fore-body, in consequence of the surface of the after-body usually presenting a more tapering and a more perpendicular surface to the water; and which causes the axis of rotation to be further aft than it would be if the fore-body and after-body were of the same form.

A ship that swims much by the stern, will, in consequence of that circumstance, have a larger surface for lateral resistance abaft midships than before it: this will cause the axis of rotation to be further aft, and that in a measure in proportion to the difference between the draft of water aft and forward. Again, the force of the water against the rudder when put over, tends to diverge the axis of rotation a little more forward, than it would be if the power

producing the rotary motion emanated or was exerted nearer to the midships. Other circumstances affecting the situation of this axis may also be enumerated. When a ship is going before the wind, and by its force on the sails the bow is pressed down in the water, such depression causes a temporary enlargement of the surface for lateral resistance afore the midship bend, and so much less abaft it; this, for the time, causes the axis of rotation to be more forward than if no such difference had been produced. Again, when a ship is under sail, the lee bow, has, owing to her heeling, more surface for head resistance than the weather bow; this circumstance when a ship is coming about, gives the lee bow in the first instant an impulse to come round, and, for the instant, causes the axis of rotation to be a little further aft, than the situation assumed by it afterward. And when a ship inclines under sail, the lateral surface for resistance becomes more perpendicular at the windward side, than at the lee side: hence, when a ship first begins to come about, the windward side of the fore-body being more upright, and the leeward side of the after-body less so, the centre of lateral resistance will at that juncture be more forward than when afterwards she gets upright; and when she heels on the opposite side, this centre will then diverge the other way, or be more abaft the midships than it was at the instant of her being upright; and the axis of rotation will vacillate accordingly. When a ship is sailing to windward, the lateral pressure is increased on the lee side, by the lee way, and by it diminished as much on the weather side; and when a ship first begins to tack, the weather side forward, in consequence of the diminished pressure there, meeting with less resistance; and the lee side aft, in consequence of the increased pressure there, meeting with more resistance; the centre of lateral resistance will, just at the commencement of veering round, be further aft than immediately afterwards; and the situation of the axis of rotation will diverge accordingly. And lastly, when a ship is coming about, the bow by her headway gets out of the channel of the water that was accompanying her in her course, while the stern is still in it: this gives the after-body a partial impulse, and tends for the time to shift the axis of rotation more forward. All these observations tend to shew how remarkably vacillating and evanescent the situation of the axis of rotation must be; and to prove that it has no stedfastness whatever in a ship under sail; and that its precise situation, while she is in motion, can be defined only transitorily.

76.—The rotary motion of a ship, whether arising from the action of the water against the rudder, or from that of the wind against the sails, or from any other cause whatever, will always centre at the axis of rotation. The power of the rudder in steering a ship is augmented in proportion to its greater distance from the axis of rotation, whether it be in respect to a long ship or a short one. A long ship, however, can never come about so quickly as a short ship,

because the extremities of a long ship move in a larger circumference from the axis of rotation; and having in consequence a greater distance to perform, will take the more time in proportion to come round.

The foremast sails on board a ship have more power to produce rotary motion, than those have which are nearer the midships; and those sails which are perpendicularly over the axis of rotation have no such power whatever. A smaller power would traverse her round this axis, if applied at the end of the jib-boom, than if nearer the foremast. The power of the sails in this respect always concentrate at the axis of rotation: and, in estimating the power of the respective sails, as in relation to their effect at the axis of rotation, regard must always be had to their distance from it, as well as to the surface of the sails. When a ship is close hauled in sailing to windward, if a larger surface of sails than requisite to steady her course, happens to be set afore the axis of rotation than abaft it, her head will fall off from the wind, and the ship will require a lee helm to steady her course. And, on the other hand, if a larger surface of canvas than so needful is spread abaft the axis than afore it, her bow will fly up to the wind, and she will then require a weather helm to steady her course. Such operations and effects can be readily adjusted or counteracted on board a ship, by practical means, without the aid of science, even if any assistance could at such times be derived from it. And so also as it relates to any unsteadiness in her course, or yawing about, produced by the incessant vacillation of the axis of rotation, such can be met thus promptly, only by practical manœuvres, since the aid of science is not momentarily available; nor can it be rendered applicable to such instantaneous changes; the preventions of which baffle the efforts of art, and bid defiance to science.

SECTION VIII.

THE CENTRE OF RESISTANCE, AND THE CENTRE OF PROPULSION.

The two centres described, and their situation defined.—In what manner one is operated upon by the other.—The centre of resistance, a moving point, and from what causes.—Its situation discriminated.—The situation of the centre of propulsion, liable to the same changes as that of the centre of resistance; and also to a peculiar one as described.—The manner pointed out, in which these two centres are operated upon; as in respect to the axis of rotation, and by the sails of a ship, and by the rudder.

77.—The centre of resistance now to be considered, must be understood as that of the resistance wholly relating to the forward progress of a ship; and as being totally distinct and different from

the centre of *lateral* resistance, treated on in the immediately preceding section. And the centre of propulsion should be considered as that point at where the forces producing that progressive motion are supposed to be concentrated, and at which to exert their efforts. This latter centre is, in some cases, termed the centre of percussion.

The centre of resistance in a ship is situated in midships: it is the centre of the area, presented to the resistance of the water, or a point where the total resistance which she meets with in passing through the water, may be supposed to be concentrated at. But in order to represent the nature and situation of both these centres clearly, imagine a plane surface of the form of the immersed part of the midship bend of a ship, to be exposed to the resistance of water; and that to be sustained by a force exerted behind it at a single point, so that the resistance against every part of the area around it was evenly sustained and balanced at this point; then, that point would be the centre of resistance, or the centre of the area of the plane. And imagine again the force behind, acting at this same point, to push the plane forward through the water, then that point would be the centre of propulsion, at which point the force would be concentrated in pushing the plane forward, and the resistance against every part of the plane evenly poised. Hence, the centre of resistance, and the centre of propulsion, in meeting at the identical point, act in direct opposition to each other; and the power of the resistance, and the force of propulsion, ever will be precisely equal, and equably opposed to each other.

78.—The centre of resistance is liable to changes in its situation, by the motion of a ship, and by any variation in her position; and these changes take place in the situation of this centre, both in respect to the athwartship-direction, and the fore and aft direction, as well as in the up and down direction. When she reclines on one side, the area of resistance then becomes larger at the lee side, and smaller at the weather side; and the situation of the centre of resistance, or of that area, undergoes a corresponding change the athwartship-ways, by shifting to leeward of the middle line. When also either her head or her stern may happen from any cause to be temporarily depressed, a change in the situation of the largest area of resistance, either more forward or further aft will commonly take place, and the centre of resistance will shift either more forward or aft accordingly. And when the stern happens to be depressed in the water, the area of resistance of a ship generally becomes enlarged under the flat of the floor, close abaft the midship bend, from which cause the centre of resistance will change its situation vertically, and shifts lower down according as the enlargement produced on the area below may occasion. Hence, it is evident that the centre of resistance, as it respects its situation in a ship, is a moving point, shifting with her various motions and positions.

The centre of resistance should not therefore be supposed to be

situated invariably at the midship bend (or dead flat,) since it does not always happen that the largest area of resistance is at dead flat, particularly if a ship happens to swim much by the stern; it would, in the case of a ship drawing more water aft than forward, depend on the turning of the lines under the lower part of the bottom close abaft dead flat, or on the rising of the floor timbers next abaft it; as well also as upon how much deeper the body might happen to be in the water a little further aft from dead flat than at it. A larger area of resistance usually presents itself a little abaft dead flat, when a ship swims by the stern; and what is meant by the centre of resistance, is the centre of the largest area, wherever it may happen to be described, by the form and position of a ship. Therefore the centre of resistance ought never to be considered as being the centre of the immersed part of the area of dead flat; it would be equally erroneous to consider it to be so situated, as to suppose the centre of displacement to be always situated in the section of dead flat; indeed, the form of a ship is of so diversified a nature, that the centre of the area of dead flat, the centre of displacement, and the centre of resistance may all at the same moment be in different situations; since it must be highly improbable that the displacement of the body afore the section of dead flat, would ever chance to be exactly of the same bulk as that abaft it; and equally as unlikely, that the displacement afore the centre of the largest area of resistance might ever happen to be exactly of the same bulk as that abaft it.

79.—The centre of propulsion is subject to the same changes of situation as the centre of resistance; they usually accompany each other in their shiftings, or diverge simultaneously. The centre of propulsion is, however, exclusive of those changes liable to a peculiar variation in its situation; namely, from its point of force being sometimes deviated from, or not always bearing exactly to the centre of resistance, as will thus appear. When a ship is under way, the collective force arising from the pressure of the wind on all her sails forward and aft, act at the centre of propulsion to move her forward; in opposition to the power of the resistance of the water, as concentrated at the centre of resistance. If there then happens to be (especially in sailing near the wind,) a larger spread of canvas than is needful to steady her course, set afore the axis of rotation than there is set abaft it, such part of the force accruing from that portion of the canvas forward, which so exceeds the spread aft, cannot act at the centre of resistance without the aid of the rudder; and would be ineffective, but for the action of the rudder to bring the centre of propulsion to bear, and balance the force at the centre of resistance.

It ought, however, to be observed, that the operation of the rudder, in thus bringing these two centres to bear, tends in a measure to diminish the force at the centre of propulsion, and thereby to lessen the velocity of the ship, and this in proportion as the

power exerted by the water against the rudder may, in its action, happen to check her headway. But, although when the centre of effort, or the force of the whole area of the sails set, is so situated as to balance at the axis of rotation, such deviation in the centre of propulsion from the centre of resistance does not then occur: it must not be inferred from this, that the centre of the force of the whole area of sails set (which centre is termed the point velique,) ought to be exactly perpendicular over the axis of rotation, since the stronger resistance of the water against the lee bow, always gives to the head of the ship an impulse to veer to the wind; and, therefore, to counteract this impulse, it is necessary that the centre of the force of the sails should be rather afore the axis of rotation, and even a little more than is in such respect needful; and this, in order to render a small weather helm requisite to keep her on her course, that the ship may, by carrying a weather helm, be better under the command of her rudder, when tacking. Still, the spread of canvas should always be regulated so that the ship may have only a moderate weather helm, that her headway may not be impeded but as little as possible by the action of the water against the rudder.

SECTION IX.

THE CAPACITY.

What it comprises.—Its magnitude always greater in large ships, in proportion to their area of resistance, than in smaller ships.—Its variation in respect to the form, and to the principal dimensions of a ship, as relating to their tonnage; and also as to their area of resistance.—The advantage of increasing the capacity by length of body, and diminishing the area of resistance; and the importance of combining in one view the consideration of these two objects, while designing the draught of a ship.—In what manner the capacity can be computed.—The rule for measuring the tonnage of a ship.

80.—The capacity of a ship comprises her bulk and extent of dimensions, in length, breadth, and depth under water, by the which she is buoyed up. Her capacity is therefore the space she occupies in the water; and as the weight of the water she displaces when at rest, will be precisely equal to her own weight, so her capacity may be considered to represent her weight, as well as to its being the bulk of that part of her body that is below water.

81.—The capacity of a ship invites much attention, seeing that in comparison with the area of resistance, it varies greatly in ships of different magnitudes; and the superior advantage which large ships have in this particular over small ones, as it respects burden, is considerable; and no less important as it relates to their velocity,

when the form of construction happens to be alike calculated for carrying of sail, since a large ship will always have a smaller area for resistance in proportion to her capacity than a small ship, although the form of midship bend might be alike in both. To illustrate this fact, conceive two ships of the exact proportionate dimensions, and of similar form: one to be 168 feet long at the water-line, 48 feet broad, and to draw 24 feet water; and the other to be of half the dimensions every way; namely, to be 84 feet long, 24 feet broad at the water-line, and to draw 12 feet water. By computing the capacity, and the area of resistance of each, it will be seen, that the largest of these two ships will have nearly as much as eight times the capacity, and but only four times the area of resistance of the smaller ship. The material difference in favour of large ships is therefore obvious: the great advantage is, however, but seldom thought of, and still more rarely duly appreciated.

82.—The capacities of different ships, that are of the identical number of tons burden, by the legal mode of admeasurement, may be far from being alike; they will vary, in this respect, according to the difference in their bulk, or fulness, at every part: a ship with a flat floor, and built very full forward and aft, will have almost double the capacity, or will carry nearly twice as much as another ship of the same tonnage, that is built extremely sharp in midships, and that has a sharp bow and a clean run. The capacity will also be different when the proportion of the principal dimensions of ships that are actually of the same tonnage may happen to vary. It will, in such cases, be by no means accordant with the tonnage, ascertained by the usual mode of measurement, since, by adding to the length of a ship, her capacity will always be augmented in a greater proportion than her tonnage would increase; and by adding to the breadth of a ship, her tonnage then would increase in a greater proportionate degree, than her capacity would be augmented. A short ship may be said to have only two ends put together; but the long ship has the two ends, and a capacious middle besides. Hence it happens, that a broad ship never carries so much as a narrower ship of the same tonnage, and of similar form of midship bend, capacity accruing in a more especial degree from length than from breadth. The legal method of ascertaining the tons burden of a ship, whether as it relates to bulk of body or to proportion of dimensions, is to such intent totally inapplicable: and the custom of building ships at a certain rate per ton, by such mode of admeasurement, is absurd, fallacious, and unjust. It is this mode of stipulation which induces the constructing of ships much too wide, in order that they may measure as many tons as possible; clumsy, ugly, lumps, out of all proportion, and subject to every bad property. Individual interest becomes opposed to fundamental science; and the improvement of shipbuilding is greatly retarded by this adverse custom. It is somewhat surprising it has not long ago been exploded, and that a mode

more equitable, to all parties, and less prejudicial to the essential qualities of a ship has not been substituted. As, for instance, the price for constructing ships might be regulated by the weight of the materials in them; or, by their actual weight when built: and this weight might be accurately ascertained by computing their light displacement, or their actual displacement as it proves to be on being launched. In respect to hiring of ships also, and in other instances relating to their employment, the present method of computing their tonnage operates most unjustly. But the attention of government appears to be at length roused; and while writing this a new act of parliament is preparing to alter the mode of measuring the tonnage of ships. The contemplated provisions must, however, prove very ineffectual, since they do not strike at the root of the evil.

83.—When the capacity of a ship is increased by length, without enlarging the area of resistance, she might be enabled to carry more sail, since she would then have a greater length of bearing on the plane of floatation to support her under canvas; and provided she is formed properly for carrying sail, her stiffness (see art. 91,) would be increased in proportion to the length added: more sail also could be spread fore and aft-ways on board a long ship, than on board a short ship, to force her through the water. And when the capacity of a ship and her stiffness is thus increased, by adding to her length, if at the same time her area of resistance could be lessened also, her velocity would be accelerated not only by the being enabled to carry more sail, but also in consequence of her resistance being diminished. It is therefore a very material object to enlarge the capacity of a ship by due length, and to contract the area of resistance as much as circumstances will allow of. And the importance of capacity, especially as it relates to spaciousness of, and length of bearing in producing stiffness, and the consideration of resistance, should always be combined in one view, when designing the draught of a ship: remembering that her capacity must absolutely be sufficiently capacious to stow and carry all she is required to take on board, and may have appending to her; but that greater capacity than so requisite, will ever prove prejudicial to her sailing, inasmuch as an additional and superfluous weight, or ballast, will then be needful, in order to bring her down to her proper bearings. And, as by lessening the weight in a ship, she will always go faster, provided she is as well enabled to carry sail without the weight so lessened: of course any superfluous weight, or unnecessary enlargement of capacity, should be studiously avoided, in respect to ships of war, that are intended for fast sailing, since they ought to be of such a form of construction, and to be stowed in such a manner as to require but as little superfluous weight as possible: (see art. 105.) Capacity can always be augmented by additional length, without enlarging the area of the midship bend, or causing any other increase of resistance, except-

ing a little more from the friction on such additional length. And as augmenting capacity by length, produces a longer bearing at the plane of floatation, and enables a ship (if constructed properly for carrying sail,) to bear more canvas and to go faster, so far length may be said to increase motion.

84.—When the capacity of a ship is required to be known, it may, when the draught of her is all completed, be computed, by dividing the immersed part of the body into many different sections in the sheer plan, similar to the stations of the frame timbers; and by laying down each of the sections in the body-plan in the same way as the timbers are done: (pencil lines will only be necessary for the occasion.) The area immersed, or surface of each section on the body-plan up to the water-line in sailing trim, must then be computed superficially; and for greater accuracy this is sometimes taken in superficial inches. The distance between each section in the sheer plan is then to be taken in inches; and the surface of each section in the body-plan taken in superficial inches as aforesaid, is then multipled by the number of inches in distance between each section in sheer plan, each one after the other. The product that must be taken for each section, is the mean between the products of two sections next together, and between every two as they follow each other, beginning from dead flat to aft, and then from dead flat on forward. Such products so taken being all added up together, will produce the capacity of the ship, or her displacement, in the water in cubic inches. These, if brought into cubic feet, and the product multiplied by $62\frac{1}{2}$, (which is the number of pounds weight of a cubic foot of fresh water,) will give for the quotient the weight in pounds avoirdupoise, of the ship and all aboard, when she is in sailing trim as corresponding to her capacity. Many modifications will appear needful during the process of calculation; particularly in the sections close forward, and in those close aft: such will be obvious in the operation; but the minutia of which, would be too tedious here to define and explain.

85.—In order to compute the tonnage of a ship, according to the present law of admeasurement, take the length of the ship from the back of the main post, at the height of the wing transom, to the foreside of the main stem under the bowsprit. From this length deduct for the rake of the stern post, two inches and a half for every foot of perpendicular height, that there may be from the rabbet of the keel up to the wing-transom. And from this length, deduct also for the rake of the stem, three-fifths of the extreme breadth. Such deductions being made will give the length of the keel for tonnage. Then multiply this length of the keel for tonnage by the extreme breadth of the ship below the wales; and that product by half of the extreme breadth. The product then shown, being divided by 94, the quotient will be what is called the tons admeasurement of the ship.

SECTION X.

THE VIS INSITA FORCE.

Its nature explained.—Illustrations.—Different from the momentum of a body moving out of water.—What constitutes the vis insita force of a ship; and the peculiar operations, and varying effect of the causes of it.—Observations on the inertia of the water, and on the inertness of a ship.—The power of the vis insita force in a ship considered, both as it relates to her weight, or capacity, and to her area of resistance, and also to her length and breadth.—Such particulars however not accurately known.—Its increase with increase of velocity considered.—Where its force is concentrated.—The importance of its effect; and the advantages which a ship derives from it, pointed out.

86.—When a ship is set briskly in motion, and the power which moves her forward suddenly ceases, she will still continue going onward, and that for some time after the power has ceased. By the impetus communicated in the giving to her motion, she persists in that motion, the inertia of rest being then changed into the inertia of motion; and as she continues going on, she will move gradually slower and slower, flagging and lingering until she loses her way altogether, and then she stops. This force that thus continues the motion of a ship, after the power that gave the motion ceases, is what is meant by the vis insita force: by mariners it is termed the ship's way; as when they say, check her way, or give her good head-way. It is the innate force or power of resisting, by which all bodies endeavour to persevere in their present state, whether of rest or of moving forward.

87.—If a ship with all her sails filled, was to be confined by a rope from going forward, and the rope was to be suddenly let go, she would not obtain her full speed all at once, but her motion would increase gradually, until she did attain it, or until she acquired a uniform velocity; and having acquired her full speed, if the pressure of the wind on her sails was then suddenly to cease, she would not instantaneously stop, but continue to go on, and in persevering to do so, would move gradually slower and slower until her motion ceased. And there is in all bodies the same persistance; to rest, when at rest; and to motion, when in motion. A ship therefore by her velocity, acquires an innate persistance in motion. This is subject to resistance from the air against that part of her which is above water; the same as occurs to the momentum of a vehicle, moving upon the land, and that part of her which is below water, becomes subject to the operation of that fluid. That the resistance from water is a very powerful obstruction to this persistance in motion, is beyond all doubt: the momentum of a stone striking the water will stop; a pendulum also will soon cease its vibrations in water, though it will continue vibrating some time

in the air, and in a vacuum a considerable time. Therefore, if the vis insita force of a ship, emanated solely from her own innate persistance to motion, it must soon be annihilated, or overcome by the resistance of water. And hence, the inference is irresistable: namely, that there must be some other effect produced by the velocity of a ship, from which the vis insita force emanates, and that too in a very especial degree.

It has been fully explained, (see art. 43,) that a ship in motion carries with her an atmosphere of water. Her velocity imparts an onward inertia to the water that accompanies her, or gives to it a persistance in motion, of a similar nature as that which by her velocity is communicated to the ship itself. A ship when suddenly impeded, is therefore urged on by the moving inertia of the water that accompanies her, as well as by her own innate persistance in motion; and it is the combined effect of the two operations that produces what is termed the vis insita force of a ship. These two operations, though perfectly distinct, act in intimate co-operation, and always exert their respective full effect, whenever a ship is moving straight forward. The distinction, in respect to the two operations can be easily defined. When a ship is urged on solely by her vis insita force, and happens to strike her bow against any object raised above the water, (such as a jetty or platform,) and she recoils, her innate force of persistance to motion is at once stopped, but the onward inertia of the water would still continue, and urge her on again to the object, and do so, perhaps, twice or thrice after recoiling from it, or as long as the water that accompanied her continued to pass her, and to move on under the jetty.

These effects can be further elucidated. When a ship is in motion, the water being in a measure pushed on before her, any temporary partial obstruction arising from the water, immediately in contact with the bow, is, in a measure, lessened, in consequence of its being so pushed on. Whenever she happens to be checked in her motion, she receives from the water that follows close after her, a shove behind, or an impulse from the onward inertia of the water, which assists her in overcoming any partial obstructions at the bow. But, if a ship suddenly changes her course, and gets out of the mass of water that was accompanying her, this effect would soon be lost, and could not be resumed again until she put a fresh mass in motion. Thus, when a ship is tacking about, and the sails shiver in the wind, and cease their impulse, as soon as she, by changing the direction of her course, gets out of the channel of water that was accompanying her, she loses the impulsion of the onward motion of the water, and has then to contend with the resistance of a fresh mass, solely by her own innate persistance in motion, and, in a few seconds, the resistance of the water totally overcomes it, or she loses her headway. For want of way, the rudder loses its power; and, but for the prompt management and aid of sails to bring her round, the ship must miss stays.

88.—When the sails of a ship are all spread, and first receive the impulse of the wind, she does not acquire her full speed all at once, but slowly, as the continuing force gradually communicates to the water an onward motion, and as it also gradually subdues the inertness of the ship. When the sails are afterwards taken in, she does not lose her motion at once, but slowly again, as the continued resisting of the water consumes the vis insita force. In these cases, there is the inertia to be overcome; in the first instance, the inertia of rest, and, in the other instance, the inertia of motion. A ship takes about one-third of a minute to get full way, and about the same interval would elapse in losing way, were she to be turned out of the mass of water that was accompanying her; but if continued in a straight direction, or in the same tract, her motion would then last much longer, and linger on for a considerable time; since, as water requires a force to disturb and set it in motion, so when disturbed and set in motion, it requires a time to restore itself to rest again.

The inertia of rest in the water, and the inertness, or motal inertia, obstinacy, or unwillingness, to motion in the ship herself, makes it at first difficult to start her, there is ever a reluctance to change; and to give a ship at starting, the same velocity which she afterwards attains, would require more than double of that force, as would maintain such velocity afterwards. Daily experience shows that a greater effort is at first necessary to put a vehicle in motion on land, than to maintain its motion afterwards, its inertness having first to be subdued; and that a strong effort is also required to stop it, owing to its persistance in motion, when set agoing. The force required to produce a commencement of motion to floating bodies, depends on their weight, and on their bulk, as well as on their form. Thus, if twenty pieces of timber floating on the water were made into a compact raft, it would then require a much stronger effort to start them, than if they were all tied in a line, one to the end of the other, having a short length of slack rope between each, so as gradually to follow each other: the inertia of rest is then divided, one piece only requiring to be started at a time; and, in consequence, that of all is the easier overcome and set in motion.

89.—The innate persisting force of a body, moving in an unresisting medium, is dependant upon its weight, or is proportional to the quantity of matter: one body that is double the weight of another, will have double the persisting force, or power to persevere in its motion. The vis insita force of a ship, so far as it relates to her own innate persistance of motion, will also be thus dependant upon her weight. One ship, therefore, that is twice the weight of another, will have double the innate force of persistance in motion; still, she might not have precisely the same proportionate increase of vis insita force, since that would have to depend as well upon the action and operation of the water, and upon other circumstances also. It is the common received opinion, that the vis insita force

of a ship is dependant upon the proportion which the area of resistance bears to her weight, (or to her capacity which is the same thing ;) and that one ship having an area of resistance, twice as large as another ship of the same weight, the former would only have half the vis insita force of the latter. The law of inertia as appertaining to floating bodies, at least so far as it relates to ships, does not, however, appear sufficiently intelligible, or definite, to determine such points with any accuracy.

Large ships have a smaller area of resistance, in proportion to their capacity, than smaller ships, (see art. 81;) and it is considered that the vis insita force of large ships, is therefore greater from two causes : first, from their superior weight or capacity ; and secondly, because their area of resistance is smaller in proportion to their capacity, than as regards smaller ships. It is also supposed, that long ships have a similar advantage over short ships, that are of the same precise tonnage ; and, that as length of body, in an especial degree, augments capacity more than it contributes to the tonnage, the vis insita force increases according to the augmentation of capacity. And it is further opined, that a short ship has less vis insita force than a long ship, each of them having the same area of resistance. These, however, are points not easily determined, or even to be very well calculated upon, seeing the vis insita force emanates from combined effects. So far as it might relate only to the innate force of persistance in motion of the ship herself, such conclusions may be nearly right in some points ; but if considered, as it relates to the combined effects that produce vis insita force, great doubts may be assumed as to their perfect accuracy in any one point. For although a larger area of resistance may sooner exhaust the vis insita force of a ship, it does not follow, that the vis insita force is less ; since, as the magnitude of the mass of water that accompanies a ship in her motion, is in proportion to the bulk of the area of resistance ; or according to the quantum displaced, and set in motion, (see art. 45 ;) the impulse of the onward inertia of the water, might therefore be supposed to correspond with the magnitude of the mass put in motion. But, however this may be, if the vis insita force of a short ship was to be equal to that of a long ship, of the same area of resistance, and to be consumed in an equal degree by the resistance against that area ; yet, it must doubtless be consumed in a much greater degree by a short ship, from the checks she would, in consequence of her shortness, be subject to from the pitching motion, since she plunges with her bow more perpendicularly into the sea than a longer ship would do, and of course encounters more violent shocks.

90.—The momentum of a heavy body is the quantity of motion, or force, in a moving body ; and is always equal to the quantity of matter multiplied into the velocity. The momentum of a body, weighing ten pounds, and moving with a velocity of three miles

per hour, is equal to that of a body of five pounds weight, moving at a velocity of six miles per hour, (ten times three, or five times six, being thirty.) This may hold good with respect to bodies on shore; but it should be remembered the momentum of a ship is assimulated with the action of the water; and being in a measure dependant on the operations of that fluid, a very different result might be expected to be produced. It is but reasonable to suppose that when the velocity of a ship is doubled, her own innate force of persistance in motion must also be doubled: and hence has arisen the received opinion, that the vis insita force of a ship always increases precisely as her velocity increases; that is to say, that when she is going at the rate of ten miles an hour, her vis insita force is twice as powerful, as it is when she is going five miles per hour. And whence also has arisen the inference, that the effort required to stop her, would, in the former case, be double of that required in the latter case. Such conclusions, however, may be very far from being correct, since it is not known for certainty, in what degree the motion of the onward inertia of the water that accompanies a ship is quickened, or increased, in proportion to any increase in her velocity; whether or not it is precisely as the velocity increases. Admitting it, however, to be the case, that when a ship moves at double velocity, the water she carries with her moves also with double velocity, it should then be remembered, that water by moving with double velocity, acquires four times stronger impulse; consequently, if a ship under full way was to be suddenly retarded by any temporary obstruction, the push she would receive behind from the onward inertia of the water that accompanied her, would, in its efforts to subdue such obstruction, be *four* times as strong; whereas the efforts accruing from her own innate force of persistance in motion would only be *twice* as strong with double velocity. The difference between the vis insita force of a ship, and the momentum of a heavy body on shore will therefore be apparent, and whence the cause of such difference arises, since the former may very reasonably be supposed to increase more in power than the latter by increase of velocity: the degree of variation is, however, most difficult to find out.

91.—The impulse produced by the vis insita force is always concentrated and applied at the centre of propulsion; and the centre of inertia is ever situated at the centre of displacement. In contemplating the real nature of the vis insita force, it must not be imagined that it ever produces velocity, since it is by the velocity of a ship that the force is brought into action. It only tends to make her velocity more regular and uniform; and to assist her in continuing her motion at those intervals, while the power that causes her motion, may, from any circumstance, alternately vary or be diminished, as happens from the irregularity of the impulse of the wind on the sails. And to assist her also in subduing any sudden and temporary obstructions, such as arises from the concussion of

the waves, or from the turbulence of the elements. As well as to help her to overcome the temporary checks she may receive from plunging her bows in the water. And to overcome the shocks and jerks, incessantly produced by the violence of her motions, by the swaying of her masts and rigging. Its operation under all such contingencies, tends to equalize her progressive motion; and, by thus enabling her to persevere more steadily in her motion, it facilitates her progress. And as a ship might not get on so fast without its aid as with it, it may so far, and in such respect, be conceived as promoting her speed; but by no means should it ever be considered as a first cause of velocity. The operation of the vis insita force on the progressive motion of a ship may be considered as of a very similar nature to that of a heavy fly-wheel on the movement of machinery. The momentum which is imparted to the wheel, equalizes and steadies the motion of the machinery; and this effect emanates from the power which moves the identical machinery that whirls the fly-wheel round. And, in like manner, the effect of the vis insita force on the motion of a ship, emanates from the power that gives to her the velocity that produces the force.

SECTION XI.

THE STABILITY.

Its properties defined, and on what it depends.—How it increases with increase of capacity.—The motions operating upon it described: that of rolling, pitching, and heeling.—The difference in the degree of stability, as in regard to breadth and depth; length of bearing, and length in the ship; length of floor; and form of fore-body.—Also as it relates to the proportion of capacity in the fore-body to that of the after-body in the pitching motions; and to the form of the timbers, as it respects rolling and stiffness.—The proper form of timber described that is best adapted to resist rolling, and promote stiffness; and the height and form of upperworks.—Stiffness, as acquired by a ship from construction; and as by weight.—Stiffness and rolling, as depending on the height of the centre of gravity, illustrated; and the proper height shown.—Remarks on the stowage of a ship as affecting her stability.—The most judicious mode pointed out.

92.—Stability is that quality in a ship, which enables her to keep herself more steadily on the water, when exposed to rolling and pitching motions; and that assists her also in keeping herself more upright, or that gives to her stiffness under the pressure of the wind on her sails. Its acquisition is of the first rate importance to a ship, since her safety, as well as her power of action under canvas, is dependant upon it. The stability of a ship emanates

from two causes; namely, from her form, and from the distribution of the weight on board; and as comparing the stability of one ship with that of another, they being of the same form but of different magnitude, it will be in a degree in proportion to their respective capacity. But as it relates to all ships, whatever may be their capacity, their stability in proportion thereto, must always depend on the form of the body, and upon the mode of the stowage of the weight on board.

Hence, stability may be said to be a power derived from the relative positions of the centre of gravity, and the centre of displacement; or from the force accruing from their position to each other, as operating in resisting the rolling and pitching motions, and in the giving stiffness under canvas; and as the situation of these two centres wholly depend on the form of the body, and upon the mode of stowage of the weight on board, consequently, stability must also depend on the form and stowage. Stability always increases with the magnitude of the capacities of ships; that is to say, provided those brought into comparison that are of different capacities, have a similar form, and are stowed alike, and with proportionate weight. In such cases, a ship with a large capacity will ever have more stability than another with a smaller; and the proportion will especially depend on the difference afforded by the capacity in the spaciousness of, and in the length of bearing at the plane of floatation.

93.—But it will be proper to explain the nature of those motions which a ship is subject to, that operates on her stability. Rolling, is that motion, when a ship vibrates, or rocks on the water from side to side; she moves to and fro on her axis of inclination: this is an imaginary axis, passing from head to stern, and is always situated and continually keeps level with the surface of the water, and is ever in a line parallel to the horizon, passing lengthways through the centre of motion, (see art. 70 and 71 :) and while rolling a ship is urged to an equilibrium with an accelerated motion; which acceleration causes her to pass the upright position, and to go beyond it the other way, tending to give the ship a sort of vibratory motion on her axis of inclination.

Pitching, is that motion displayed by a ship when she rises and falls with her bow and stern alternately in and out of the water. This motion hinges on her transverse axis, an imaginative axis passing across from side to side in midships, which axis is always situated and constantly keeps level with the surface of the water, and is ever in a line parallel to the horizon, passing athwarthships through the centre of motion: (see art. 72.) In pitching, a ship is urged to the horizontal position with a motion rather accelerated; which acceleration has a tendency to make her pass the horizontal position, and to go somewhat beyond it the other way; or to give to the ship a vibratory sort of motion on her transverse axis, similar to that produced on the axis of inclination by rolling, only much

less in degree. In lofty short waves, the bow will ever rise by an accelerated motion, and be retarded in its plunging, since the deeper she plunges, the more she enlarges her displacement forward; and her fall is therefore retarded by the additional buoyancy acquired while plunging, as well as by the resistance of the water in striking, or pitching into the wave; and her bow, being by the plunge immerged deeper than its specific weight allows, and acquiring thereby additional buoyancy, it will, on rising again, be lifted with an accelerated motion, and this further quickened perhaps by the coming wave. The stern will also rise with an accelerated motion, in consequence of being deeper immerged, or of its obtaining additional buoyancy by the fall; and it will fall with a retarded motion, owing to the increasing of its buoyancy while falling, and to the resistance it meets with from the water, in dipping into it. And thus, alternately, the bow rises with an accelerated motion, while the stern falls with a retarded one; and the stern rises with an accelerated motion, while the fall of the bow is retarded by the plunge; and the effect of the motions thus produced, hinging at the transverse axis, is resisted by the stability of the ship, in its efforts to preserve the horizontal position.

Heeling is when a ship reclines by turning on her axis of inclination, as happens, when the pressure of the wind on her sails causes her to lean on one side. As by the efforts of stability, in preserving the upright position, the rolling motion is resisted, so the heeling of a ship under canvas is also resisted by her stability, in its efforts to keep her upright. By it she receives a support, or derives a power that assists her in keeping herself uprightly in the water, under the pressure of the wind on her sails; this is denominated stiffness; and the more erect a ship keeps herself, the greater is said to be her stiffness; and the stiffer a ship is, the more sail she will carry, and consequently the faster she will go.

Analogous to heeling, there is a variation of position hinging on the transverse axis of a ship, as when she is under sail, and going before the wind; the pressure of the wind on her canvas then tends to depress the bow, and to elevate the stern, or to bring her more by the head; and this pressure operates in opposition to the efforts of stability, in preserving the equilibrium. This variation of position being of a continuous nature, and not to be obviated by form of construction, it is very advisable that all ships, but especially short ones, should draw rather more water aft than forward, than what might be requisite for them to draw more aft than forward, in other respects, (see art. 98,) in order to allow for such depression.

94.—The co-operation of the centre of gravity, and the centre of displacement, at the centre of motion, to preserve the equilibrium of a ship, in opposition to the power that disturbs it, has been fully illustrated: (see art. 66 and 71.) It may, however, be here briefly repeated, that the centre of gravity is a fixed point; and the centre of displacement is a shifting point, moving toward that side or end

which becomes more immersed in the water, at the time a ship either rolls or heels, or when she pitches. And the greater the body of water then displaced at one side, or at one end, more than at the opposite, the stronger will be the co-operative effect of the centre of gravity and the centre of displacement, at the centre of motion, in resisting the power that disturbs the equilibrium of the ship; or in other words, the greater will be her stability.

A ship that is broad and shallow may be stiffer under canvas, and might not roll so much as another ship of the same capacity, that is narrow and deep; but either of them would be more subject to pitching, than a longer ship of the same capacity. The want of stiffness is often not so much to be attributed to insufficiency of extreme breadth as to the diminishing of that breadth along the plane of floatation too suddenly, from midships toward forward and aft; since that both lessens capacity and weakens the line of support. A long ship that has a long spacious line of bearing at the plane of floatation, continued in a fair curving line from midships, with a good breadth toward the bow and quarter, and that has also her greatest breadth every where a little above the plane of floatation, will pitch less, roll less, be stiffer under canvas, and able to carry more sail, than another ship of the same admeasurement in tons that is shorter and broader, and with less length of bearing. Two ships of the same breadth and draft of water, but one being longer than the other, the long ship having the more capacity, her power of carrying sail will increase, in proportion as her augmented capacity affords more length of bearing on the plane of floatation: that is to say, if both ships are alike formed for stiffness, and are stowed in a similar manner.

A long floor also possesses advantage in some respects; but when a ship has a great length of floor, the lines of the bottom cannot be formed with so long a taper forward and aft: and if there is not a sufficient length of taper to ease the head-resistance, and to lessen the suction in the fullest degree, of course she could not go so fast. Therefore, although a long floor with less rising forward and aft may lessen pitching; and a full bow derive more support when falling in a sea, than a sharp one; yet, owing to its thus increasing the total resistance, such form cannot be adopted for fast sailing ships. Short ships with sharp bows and short floors are certainly liable to pitch deeply in heavy seas; but if a ship is long, and has a good length of bearing at the plane of floatation, she would pitch much easier, notwithstanding her having a short floor and a sharp bow, since pitching is never so sudden or so precipitous a motion in long ships, as it is in short ones. In laying off the fore-body, and in giving it a proper length of taper, it will, however, be highly expedient to avoid all hollow lines in the bow, in every direction, since hollow lines lessen the support of a ship when pitching, and not only so, but increase her resistance: those hatchet-faced bows are of the worst description: (see art. 40.)

The capacity of the fore-body to that of the after-body, is also a matter of much consideration, as it relates to the stability of a ship; they should be in a degree proportionate to each other, for, when the fore and after-bodies are not duly balanced, it will either cause her to pitch very much, or to be in danger of being pooped when the seas run high. A ship having a sharp fore-body and a full after-body, will plunge her bow deep and violently. And a ship with a full bow and a clean run, will, particularly in carrying sail upon the wind, pitch more than one having a sharp bow and a clean run: the full bow will rise suddenly with the wave, and there being no corresponding capacity aft to support her, she will dip her stern deep, by which her bow would be still more elevated, and rise so high, that at the next plunge the ship would dash her bow with greater violence against the sea, than if she had had a sharp bow, which, (in consequence of its sharpness,) had not have risen so high.

94.—Nor does it require less circumspection and attention in laying down a ship, to give to her that form of body, as will produce a due degree of stability in the sideway motions. In rolling, the form of the body usually shifts the centre of displacement; and the form which shifts it the most, will roll the least. That shape of midship bend, which approaches the nearest to a semicircle, is the most liable to roll: not only because the centre of displacement is so little shifted by such form when rolling, but also, because a circular form produces neither protrusions nor straightness of form in any parts, or any unevenness of line to catch and operate against the water, to resist the motion of the body in it while rolling. Hence, the less the curves of the timbers approach to a segment of a circle, the more the rocking motion would be resisted by the form of the body; and rolling depends thus much on the form of the body in such respect. Stiffness of body, as derived from construction, may be most importantly increased by its form, within the space extending from a little above to a little below the plane of floatation. Such form in this part that affords additional stiffness will also resist rolling, as will presently be shown; but the projections and flatness of parts, or irregularity of curve in the form of the timbers below, as just described, may neither augment nor diminish stiffness, and yet, as before observed, are very material in resisting the rolling motion.

With a view, therefore, to ascertain the form of the curves of the timbers along the midship part of a ship, such as will conduce to stiffness as well as lessen rolling; and such as will combine both objects with as little prejudice to the ship as possible, in any respect, it will be needful to know how much higher above the water-line, (that is, the line described by the water round the ship, when she is in sailing trim and in an upright position,) the surface of the water will reach up to on the lee side, at the time when the ship heels the most under sail; and which height, at every frame timber

all along the midship body, or length of bearing, should, in every ship, be the height of the greatest breadth. This fictitious line of breadth, will be found to rise higher above the water-line at the midship frame, than it will do further forward and aft; or it will form a cambering line. It will also be requisite to know how much the surface of the water will be below the water-line on the weather side, at the time the ship so heels; or the height of its surface on that side, at such time, at every frame along the whole length of bearing: this height will be found to be more below the water-line at the midship frame, than further forward and aft; or to form a hanging line. Between the height first mentioned, (that is of the greatest breadth,) and this last-mentioned height, the line described by each timber, all along the midship parts, or line of bearing, should spread out at least as much as that it may be perpendicular on the windward side, at the time when the ship heels the most under her canvas; observing, that the situation of the timber where bisected by the water-line, must not be in the least altered. No timber should spread out less, but more than this; and as much more as the form of the timber will allow it, so as to curve in fair above; and below the water-line the timber must continue fair in the direction thus given it by the spreading out. The rising of the floor timber should, at least, be such, that the line from the floor heads to the keel may prove level at the lee side at the time when the ship heels the most: none should rise less than this, but they may rise as much more as may be desirable or proper with a view to due capacity. And these two lines; namely, that leading from the breadth above, and that from the keel to the floor heads, should be connected by a curve, describing the second and third futtock; and this curve should not be a fair sweep, or be alike circular at every part, but rather sudden than otherwise at the second futtock. The floor timbers in midships should be a little hollow at halfway, between the keel and the floor surmark, with a very small curve between the surmark and the floor heads, merely enough to make it break in fair into the curve of the second futtock. From the head of the second futtock, up to the height of greatest breadth, the timber should have as little curving as possible, just sufficient to take off a straightness of appearance and no more. From the height of the greatest breadth upward, it should have, and will require a suddenness of curve at that height, to break in fair with the topsides.

This spreading out of the body, between where the ship dips it in at one time, and raises it out of the water at another by her heeling, will cause her to heel less; since, when she inclines, she increases her breadth in the water on the lee side, and lessens her breadth at the surface of the water on the windward side: consequently the displacement of the water will be so much the more augmented on the lee side, and so much the more diminished on the weather side, by the body thus spreading out, than it would be

were the line of the timber to be perpendicular. Hence, the ship will acquire so much greater support when heeling: the additional difference thus made in the displacement of the two sides will impart to her so much additional firmness, or stiffness, to keep herself erect, and if the ship is (as she ought to be,) of a good length in proportion to her breadth, this advantage will be produced in proportion to the length of her bearing at the plane of floatation: (see art. 83.) Although such spreading out of the body may not be quite so favourable for resisting lee way, in consequence of its deviating from a perpendicular, or of its presenting a more oblique surface for lateral resistance; yet it keeps the ship more erect, and by being kept more upright, its position becomes so much the less oblique and unfavourable in respect to lee way. In this instance, however, as occurs in many others, it shows that no single object is ever to be pre-eminently acquired in a ship, without producing some prejudice in other respects; and that a little sacrifice must unavoidably be made in any one object, in order to afford a due attainment in another one, perhaps equally as essential. Upon the spreading out of the body, at the upper part of the bottom, depends, in a measure, the difference in the quantum of water displaced by a ship on the lee side, more than on the weather side, when she reclines: and a ship derives all her stiffness, so far as it depends on form of construction, upon the quantum of water she displaces on the lee side, more than on the weather side, when she inclines; which difference, as before observed, the spreading out of the body augments, and so far as it goes, operates more effectively in affording stiffness than any peculiar form at any other part of the bottom could produce: since, while on the one hand it adds to the breadth, and to the increasing of the displacement at the lee side; it, on the other hand, contracts the breadth, and diminishes the displacement, in as great a degree on the opposite side; thus operating in a twofold measure to augment stiffness.

It must not, however, be supposed that the difference in the displacement of the two sides of the ship, when she heels, can be estimated, or judged of, solely by the difference shown at the plane of floatation, as by how much the ship may dip the one side more in the water, and rise the opposite side more out of it, since the body below always partakes of the same motion, and undergoes a corresponding change of position: the bottom at the keel will shift to windward, or the middle line there will become to windward of a perpendicular with the centre of gravity as shewn at the time when the ship heels; and the higher that centre is situated, the more it would be thus shifted by the heeling of the ship; and if this centre was to be situated at the surface of the water, and the depth of the immersed part of the ship was to be equal to half her breadth at the water-line, in such case, the bottom at the keel would shift about as much to windward, as the weather side would rise out of the water, or the lee side be dipped into it; and then the difference in

the displacement of the two sides would have to depend on the form of the different frame timbers; upon how much when such change of position takes place, the bulk would be diminished to windward, and enlarged to leeward by the form given to the timbers, since, if the section of the timber then formed a semicircle, the centre of displacement could not shift in the least. The importance of the form of the timbers below, with a view to creating difference of displacement, must, for this reason, be obvious. In respect to the form of the body above, it will also be evident, that the more bulk a ship dips into the water, when heeling one side deeper into it, and the more bulk she, at the same time, raises out of the water at the opposite side, the greater must be the difference in the displacement of her two sides from this cause. Her stiffness, when heeling, must always very materially depend upon the difference in the displacement of the two sides at the upper part of the body as produced by the dipping of one side more in the water, and raising the opposite side more out of it. Hence, it must be obvious, that the more spacious the body of a ship is at the plane of floatation, or the more the capacity is enlarged thereabout; and the longer the line of bearing happens to be; the greater must be the difference in the displacement of the two sides at any degree of inclination, and, of course, the greater the stiffness of the ship. The importance of a long spacious line of bearing, as well as of the spreading out of the body just described, must therefore be manifest; and the advantage of both, in producing stiffness, should always be resorted to and combined; and the bulk of the body down below should be diminished in a corresponding degree. The advantage emanating from the spreading out of the body, and the peculiar manner by which it is derived, can be displayed in another point of view. Suppose the body of a ship instead of thus spreading out, was to be perpendicular from the second futtock upward, in such case, the ship, when heeling, would increase her breadth at the surface of the water, no more on the leeward side than it would be increased on the windward side; and no such additional difference in the displacement of the two sides could then arise, as might have accrued had the breadth being increased to leeward and diminished to windward by the spreading out of the body. Nor should the disadvantage produced by the protrusion of the second futtock at the weather bulge, so far out to windward of the centre of gravity escape observation.

In continuing the line of the timber from the height of greatest breadth upward, the form of the timbers along the topsides is not so very material as it relates to the stiffness of a ship: were they to tumble home sufficiently to become upright at the lee side, when the ship heels the most, it would unquestionably conduce the most to her stiffness: they may, however, tumble home less, or even to please the eye, with but little prejudice in such respect, and some advantage in other respects. A ship that has shallow topsides, in

proportion to her depth under water, will be all the stiffer for it; and will also hold the less wind when working to windward. Lofty upperworks makes a ship leewardly and crank; and together with tall ~~taut~~ masts, (which increases leverage,) to roll heavily, to strain, and to labour hard in a sea. Height ever militates against stability. The spreading out and proper form of body before pointed out, will not only promote stiffness, but would also resist the rolling motion, since at every lurch there would be a straightness of surface presented, both at the upper part of the bottom, and below the floor heads, striking obliquely against the water to resist the rolling motion, and a suddenness of curve at the second futtock to catch the water, and check the motion,

95.—Those ships that derive stiffness under sail from the form of their bodies, are less liable to roll than those are which, in order to obtain stiffness, require to have a great weight put on board: and more especially so, if that weight is obliged to be stowed low down. And a ship that is stiff from construction, is also better adapted for sailing fast, than one, which in order to carry the same quantity of sail, needs so much greater weight to be taken on board, inasmuch as such weight sinks her deeper in the water, and enlarges the area of resistance. Increase of breadth would doubtless make a crank ship stiffer, and it might possibly lessen her rolling; yet extreme breadths, as well as extreme depths, will cause a ship to roll excessively. Besides, breadth at and below the water-line, (that is the line described on a ship by the water when in sailing trim,) ought never to be resorted to for this purpose, when it can possibly be dispensed with, since it enlarges the area of resistance: in order to acquire stiffness, it is rather the form of the body, and a long capacious bearing, and a good increase of breadth a little above water, that should have studious attention, in preference to breadth in the water; and in preference also to the recourse of increasing the weight in a ship. But to proceed on with the consideration of the other essential object upon which the stability of a ship is dependant; namely, the stowage of the weight on board. In expatiating upon which, it must be understood, as always supposing the weight on board to be such, as is sufficient to bring the ship down to her proper bearings in the water; for when there is not sufficient weight for this purpose, the stowage of it will, in consequence, require to be very different; the centre of gravity, in such case, must necessarily be brought lower down, and after all the ship possibly would be still crank: at any rate by the lowering of the centre of gravity she would roll heavier. Such a case, therefore, must not be considered as applying to the observations about to be made. It is here supposed, that the ship actually has, as she ought to have, a sufficiency of weight on board to bring her down to her intended line of floatation, or to her proper draft of water, when in sailing trim, (see art. 105:) and it should also be here borne in mind, that large ships require greater stiffness than

small ships, since equal inclinations might prove fatal to great ships, while smaller vessels might incur no danger whatever by heeling as much.

It has already been explained, (see art. 59,) that when a ship heels, the centre of gravity must always be situated to windward of the centre of displacement; or, (which is tantamount,) must be below the meta centre, in order to afford the essential counterpoise to the power that heels her; since, whenever the centre of gravity is not to windward of the centre of displacement, the ship can derive no stability whatever in her sideway motions from the weight on board. The further distant the centre of displacement happens to shift to leeward of the centre of gravity, at the time a ship is inclined, the stronger will be the co-operative force at these two centres, as exerted at the axis of inclination, in the resisting the power that heels her. By lowering the centre of gravity, the distance between these two centres, as it relates to their windward and leeward positions, increases; and the more the centre of gravity is lowered, the further they will become thus apart. Hence, the lower the centre of gravity is situated, the greater must be the stiffness that a ship would derive from the weight on board. But then it should be remembered, that in proportion as the centre of gravity increases its distance below the centre of motion, so the force of the centre of gravity to roll the ship, increases, and operates to incline her the more at every roll; to produce deeper lurches, and to cause jerking uneasy motions, since the oscillations on the axis of inclination must ever become stronger according as the distance of the weight (or centre of gravity) increases below this axis. So that although lowering the centre of gravity might tend to augment stiffness, it would tend also to make a ship roll the heavier, and to create unsteadiness.

Hence, the centre of gravity ought never to be placed lower down than may be requisite to produce such a portion of stiffness, as may, together with the stiffness acquired by the ship from her form of construction, prove, under all contingencies, amply sufficient. If the centre of gravity was to be situated a little below the surface of the water, at the time a ship is upright, so much so as to be on a level with the centre of motion, when she heels the most under sail, the two centres when thus situated, will be at the nearest point of union, in every of her positions: and a ship ought to possess such a degree of stiffness, from her form of construction, as may, with the additional stiffness obtained from the weight on board, when the centre of gravity is at the height just mentioned, prove together, or in conjunction, amply sufficient. The rolling motion would be urged, or aggravated, but very little by the weight in a ship, when the centre of gravity, operated so closely to the centre of motion; the force of the former ever increasing with its distance from the latter: and in consequence of these two centres being so closely together, the motions would not only be softened, but the

lower and upper parts of the ship, and the masts would partake more equably of the motion, or of the centrifugal force.

Thus, when a proper form of body for stability is combined with such an adjustment, in the height of the centre of gravity, ample stiffness is thereby acquired; the rolling motion is also resisted, and very little aggravation to that motion accrues from the force of the centre of gravity. But if a ship was to be so very injudiciously constructed, as not to acquire by her form a sufficient degree of stiffness, when the centre of gravity is situated at the height just mentioned, there would then be no other alternative but to bring the centre of gravity lower down; and as much lower as might prove amply sufficient to enable her to sustain the power of the wind on her sails, notwithstanding the inevitable consequence of her rolling heavier; since it is indispensable for a ship to have always not only a sufficient, but also such a degree of stiffness as may much exceed any efforts she may ever be exposed to, to upset her.

When a ship is constructed for any purpose which precludes her from having a proper form or stiffness, in such case it must be observed, the higher the centre of gravity is required to be placed in the ship, the more necessity there would be for breadth at the water-line; and the lower the centre of gravity might be obliged to be situated in such a ship, the less occasion there would be for breadth, since by bringing the centre of gravity low down, even a narrow ship may obtain sufficient stiffness. And lowering the centre of gravity, would doubtless be an effectual recourse for augmenting the stiffness of any ship, or for keeping her more erect under canvas; but then, it should be remembered, the rolling motion would, by such recourse, be increased; a consequence of baneful tendency, and often of serious effect, and on every consideration, ought always to be avoided as much as possible. Whenever the advantage of greater breadth at the water-line, as in its producing sufficient stiffness, can be acquired by such a form of construction as will produce the same stiffness, or allow in like manner of the centre of gravity being brought to the most desirable height, such form of body should be embraced or substituted in preference, and the increase of breadth studiously avoided; since the additional breadth at the water-line, by enlarging the area of resistance, would most assuredly impede the velocity of the ship.

96.—But the centre of gravity might be situated at the most desirable height; and a ship might also be of the most proper form to acquire stability; and yet she might prove very uneasy at sea. This must ever be the case, when the weight on board happens to be stowed in an improper manner. With a view to soften the motions of a ship, or to ease her in her rolling and pitching, care should be taken to stow the heaviest articles on board, well in midships; as for instance, toward the transverse axis, to ease the pitching motion; and toward the axis of inclination, to soften the

rolling motion. Some, however, prefer, in the latter respect, increasing the weight at the sides, as by winging the ballast; but this mode, however it might ease the rolling, by making the roll longer, would tend also to increase the centrifugal force, and to make the roll deeper. If too much weight is stowed forward in the bow of a ship, she will plunge violently in a sea, and, if near aft, she will send with her stern deeply in the water, and run a hazard of being pooped. No heavy articles, or any great weight should ever be placed at or near the extremities of a ship, nor close to the sides along midships. The stowage forward and that aft should be regulated in such a manner, as that the weight of the water displaced by the fore-body may be rather greater (but not so much as to strain the ship,) than the weight of the fore-body itself, together with that of what is stowed in it, and the same with respect to the after-body, in a manner for the two extremities of the ship to buoy up a portion of the weight that lies in midships: this mode of stowage would make her lively in rising in a sea-way. The importance of using every precaution, to make a ship easy and lively in all her motions, must be obvious, since, by plunging her bow with violence against the waves, her speed is checked, and the shocks from pitching deep, consume the vis insita force, and together with rolling heavily, jerk and endanger the mast, and strain the hull.

PART III.

SECTION I.

ON DESIGNING THE DRAUGHT OF A SHIP.

Preliminary observations.—The dimensions of a ship considered; length, breadth, and depth.—Where best to be determined at.—The proper proportions pointed out.—Remarks on the upper water-line in the sheer plan; advantages of adjusting its height, so that a ship may swim by the stern.—The proper rake of the stem; and that of the stern-post shewn.—The station of the midship bend in the sheer plan considered; and its proper situation in a ship pointed out.—Observations on the height of the upperworks; on the sheer of a ship; on the overhanging of the counter; on the rake of the stern, and projections at the bow.

Swiftness is an object to which the science of ship-building is particularly directed; it is the pride of the ship-builder, and the delight of the mariner; and of the utmost importance to ships of war, to packets, (and to merchant ships also, when laden with perishable cargoes.) To some of my young friends there may appear a sort of mystery attached to the art of ship-building; this is often the case with young beginners, and which imparts to them a curiosity, and an eagerness to obtain an insight into the lines; and when the practical knowledge of sketching the draught of a ship is learned, an ardent desire then arises to discover of what form those lines should be, in order to make a ship sail fast. This zealous desire induces an inquiry into fundamental science; and then the designing of the draught of a ship becomes peculiarly interesting: judgment also may be acquired in the execution, and every reasonable hope entertained of successful efforts. The preceding sections being therefore familiarly understood by the practical man, who has the needful insight into the lines, he will be prepared to blend the science and the art more intimately together, and will clearly perceive, that unless the science is combined with practice, improvements in the art of ship-building must ever go on languidly; and that perfection must almost be despaired of without such union. He will also see the absurdity of ships being built by the rule of thumb, or to accord with the vague notions commonly entertained by those having only operative knowledge, and feel convinced that success must depend upon the exertions of those most skilled in the science, and in the theory of the art; being united with the exertions of those who are most skilled in the practice of the art.

97.—The proportional dimensions of a ship, with a view to the acquiring of those essential qualities that have been pointed out in the second part of this treatise, and for giving her also, as near as possible, the fine form of body to enable her to sail fast, as described in the first part of this treatise, are of the greatest importance; and it is the principal dimensions of a ship that must be primarily taken into consideration and be determined on. The superior advantages of length in enlarging capacity; giving length of bearing, and thereby promoting stability and affording stiffness beyond that of breadth and depth; has been illustrated: (see art. 82, 83, and 93.) Length is also of great advantage in sailing to windward: two ships of the same breadth and draught of water, and one longer than the other, the longest will present the greater area, or surface for lateral resistance against the water, and, of course, make less lee-way than the other; and those ships that present the largest portion of that area the most perpendicularly against the water, will resist lee-way with the strongest effect. Length unquestionably is of paramount advantage; but yet, if carried to extremes, it may prove prejudicial to a ship; inconvenient by its making her slow in coming about, and unhandy in working to windward in short boards: she could not of course be so quick and lively in her rotary motions if she was too long, as she might be if of a proportional length.

Whatever advantages may accrue, in respect to great breadth, if those advantages can be acquired by due length, excess of breadth should be avoided, since superfluous breadth below water adds greatly to the area of resistance without affording additional capacity in proportion to what is acquired by length; and it makes a ship also more leewardly under sail: (see art. 17, 31, and 82.)

A great depth below water also enlarges the area of resistance without augmenting capacity in a degree proportionate to such enlargement. It commonly makes a ship roll heavier; and often, when heeling under canvas, to present a bulk of body down below at the weather bulge, projecting so far to windward of the centre of gravity and of the centre of motion, as to tend to uplift the weather side, and to lessen the stiffness of the ship: (see art. 94.) It might be urged that a great depth below water would be advantageous in checking lee-way; because, that of two ships, both of which being of the same length and breadth, but one deeper immersed than the other, the one deepest immersed would have the most lateral resistance. But then such superiority cannot be *thus* obtained without baneful consequences; and this advantage, in order to be achieved without prejudice, must be acquired by due length, and not by excessive depth. Extremes in either of these three principal dimensions ought always to be carefully avoided; each should be in proper proportion to the other, so as to obtain from the dimensions every way a due proportion of all the essen-

tial qualities appertaining to a ship; and to avoid in each dimension, as much as possible, any predominancy that might prove prejudicial to such general attainment.

The plane of floatation, which is the seat of motion of a ship, and the plane of her support also, is naturally pointed out, as at where these proportions can be most properly ascertained and adequately adjusted. This plane is described by the surface of the water round the ship, and should be designed in the draught as the upper water-line, and intended line of floatation, or that line where the ship will swim down to when in sailing trim; and it may be considered as a most material governing line in designing the draught of a ship. The following proportions embrace by the dimensions, every way, all the essential advantages in the most desirable degree. The length of a ship, on the aforesaid upper water-line, from the after part of the stem to the fore part of the stern-post, measuring along at the water-line, should be equal to four times the breadth which the ship is of at the height of this line, measuring the breadth on this line from outside to outside of the timber at the midship bend. And the depth at the midship bend, measuring from the water-line down to the lower side of the floor timber at the keel, should be equal to one half of this breadth.

98.—This upper water-line must not, however, be considered as a level line, or as being parallel with the rabbet of the keel; it will be higher up on the stern-post than on the stem. Fast sailing ships should always swim by the stern, and never on an even keel; and smaller ships more so in proportion than larger ones, since the pressure of the wind on the sails, always gives to a ship an inclination by the head, particularly when going large: (see art. 92.) A ship also derives a great advantage in sailing to windward by drawing more water aft than forward: more surface is then presented by the after-body laterally against the water to check leeway, and it assists her steering also, more of the rudder being then immerged. Besides these, there is another advantage accruing to a ship from drawing more water aft than forward; namely, to counterbalance the effect of the increased resistance of the water against the lee bow, when she is sailing to windward. In consequence of the heeling of the ship, the lee bow becomes deeper immerged, and has a larger surface for resistance than the weather bow, which becomes less immerged, and not only so, but owing to the wind pressing the ship to leeward, the lee bow is stronger resisted in consequence of that pressure; and in proportion as the lateral pressure increases the resistance on the lee bow, the resistance on the weather bow is diminished by it. This unequal action of the two sides of the bow against the water, produces an effect somewhat similar to that of the operation of the rudder; the greater resistance on the lee bow, forces the head of the ship to windward, to which the lesser resistance on the weather bow yields: this is what mariners term griping; the head of the ship flies up to the

wind, and she requires either more head sail, or else a weather helm to counteract the effect, and to keep her steady in her course.

If, instead of dividing the water sideways, the bow of a ship had a prodigious rake below, or was formed in a slanting direction to divide the water in a manner for it to pass under the bow, no effect of this sort could be produced. And as ships are usually constructed, this effect is not so great, when the bow is either extremely full or when excessively sharp, as it is when the sharpness is in a medium degree; namely, when at that angle (similar to a rudder,) which produces the strongest effect. This angle, as it respects the action of the water against the rudder, is $54\frac{1}{2}$ degrees. A ship, with a bow of that degree of sharpness, will require the foremost to be further forward, and a greater press of head sail than one with a fuller bow, though less able to support it. This circumstance claims some attention, and requires to be guarded against; and with a view to acquire a proper adjustment in this respect, and to obviate the necessity of having the foremast so far forward, and of carrying an excessive proportion of head sail, the ship should swim by the stern, in order to augment the lateral resistance of the after-body. These several advantages, accruing to a ship from drawing more water aft than forward, evidently evince the necessity of the measure, and the upper water-line, or intended line of floatation, should therefore be adjusted accordingly. A ship may with every advantage swim two feet by the stern: no ship should ever be constructed to swim less than one foot by the stern; some require to be three feet, or even more according to their built and rig.

99.—With a further view to proper adjustment, in this respect, the stem should have a moderate rake below water, in order to ease the lateral resistance of the fore-body; so that by increasing the lateral resistance aft, and diminishing it forward to a proper degree, the foremast may not be required to be so far forward, and a proportionate quantity only of head sail become necessary, just enough to balance the lateral resistance, together with being almost sufficient to counteract the effect of the increased resistance of the lee bow in the forcing the ship's head to windward; that is to say, *nearly* sufficient, so as still to render a moderate weather helm needful to equilibrate: since a small weather helm is an advantage to a ship; it tends to check her lee-way; not only so, but a ship always answers her helm more promptly for it in tacking, comes about quicker, and is more nimble and lively in her motions. By making such adjustment, the force of the water against the lee side of the rudder, from carrying a small weather helm, and the stronger action of the lee bow against the water, will both operate in conjunction to make the ship claw to windward; and by the easing of the lateral resistance at the fore foot, the force of the wind on the head sails will be more exclusively and effectively applied on the angle of the lee bow to force her to windward. There is also

another advantage accruing from raking the stem down below: it gives the fore-body of the ship a better form for facilitating such rising of the body out of the water as may be consequent on her velocity: (see art. 19.) The stem should not, however, rake too much below, since, when a ship rests with her weight upon her keel on yielding ground, the overhanging weight of the bow, figure-head, bowsprit, &c., would, in such case, press heavily on the fore foot, and cause it to settle down, and the keel to camber toward the fore end. The stem should, therefore, have only a moderate rake below; above water it should continue upward in a feint curve so as to be nearly upright at the time the ship is in sailing trim.

The stern-post should rake but very little; merely enough to bring the after part of the rudder perpendicular with the plane of floatation. This uprightness will increase the surface of the dead-wood, which here acts more perpendicularly and effectively to resist lee-way than at any other part; and will also give more power to the rudder in steering, by increasing its distance from the axis of rotation.

100.—The station of the midship bend, on the sheer plan, is considered an interesting point to determine, and of which various opinions are entertained. If we consult nature, in the form of the fastest swimming fish, it will appear obvious, that the greatest breadth of a ship with a view to swiftness, ought to be nearer to the head than to the stern; and beyond all doubt, it would be desirable, as it respects the form of the bottom of a ship, *if considered solely with a view to velocity*, that the midship bend should be stationed well forward: as in consequence of its being so stationed, the length of the after-body would be increased, and thereby produce or admit of a longer taper and a cleaner run to avoid suction; and the longer a ship might be of in proportion to her breadth, the further it could be placed forward with such view, without creating too great a fulness in the bow.

But in this, as in many other cases relating to ships, it unfortunately happens, that no one particular quality can be achieved in the fullest degree without abatement or prejudice to other qualities equally as essential. And, in this instance, there is besides, a circumstance that claims peculiar attention: the midship bend cannot be fixed well forward, with a view to promoting swiftness, without danger to the ship as it respects her construction. Her form must be adapted to insure safety, in this respect, as well also as to enable her to be a good sea boat: and these are essential points that must be attended to as well as swiftness. In determining the most proper station of the midship bend, it should be borne in mind, that ships, from accident or necessity, may, at times, take the ground, and heel on their bulge; and the station of the midship bend that would be proper for their support, on those occasions, is not so suitable for promoting velocity, And it should be further

remembered, that the centre of gravity ought always to be situated as near as possible, at the same distance from the head of a ship as from the stern, so that each extremity may receive in an equal degree its force, in preserving the equilibrium in the pitching motions; and the centre of gravity requiring to be so situated, the centre of displacement must, of course, be so situated also; hence, it follows, that the displacement of the after-body of a ship, and the displacement of the fore-body, should be as nearly equal in proportion to each other as possible: (see art. 93.)

The safety of a ship, as in relation to her construction and her stability, in respect to the pitching motion, would make it advisable to fix dead flat (or the midship bend,) as near to the middle of a ship as possible; while, on the other hand, the promoting of her velocity would render it desirable to place it far forward: added to which latter consideration, the fore-body requires a greater fulness to sustain the force of the wind on the sails, while they are pressing down the bow; and a forward position of the midship bend would afford this requisite fulness, as well as lengthen the taper of the after-body, and lessen the suction. Therefore, with a view to embrace every advantage as equally as possible, it is advisable to adopt a medium, and to fix the midship bend nearer to the head than to the stern of a ship. It should not, however, be stationed too far forward, for, in such case, if the ship takes the ground and heels, her bulge will not sustain the weight of the fore-body and that of the after-body on a poise; and the overhanging weight of the quarter would twist and strain her considerably. Upon the whole, the most proper station for the midship bend, taking every circumstance connected with its situation in consideration, appears to be at three-sevenths of the length of the ship from forward; measuring the length along and at the height of the upper water-line from the after part of the stem, to the fore part of the stern-post; and setting off three-sevenths of that length from the after part of the stem at that height: and this may be concluded to be altogether the most preferable situation for the midship bend of a ship.

101.—The height of the plane of floatation, or upper water-line, having been determined as aforesaid, and drawn on the sheer plan, the height of the wales, topsides, decks, and upperworks, should all be set off *from that line.* Although the form and proportions of a ship above water, may not at first glance appear to be so very important, in respect to some of her essential qualities, yet, it certainly more or less affects all her good properties. Lofty upper-works will cause a ship to roll excessively; make her less stiff under canvas; and by holding a great deal of wind, will increase her lee-way. The upperworks of a ship should be compact and snug in every respect, to hold but as little wind as possible; and should also be formed so as to receive and sustain with ease and safety the violence of the waves. They ought never to be higher than

absolutely needful; and if circumstances could admit of it there should be no poop, round-house, or forecastle, but a flush deck fore and aft, without any breaks or bulkheads to hold wind when the ship is plying to windward: a flush deck, moreover, adds to the strength of a ship; and all breaks in them, to her weakness: vessels are always found to loosen more where there are breaks than at other places. The sheer should hang very moderately; and in order to keep the bowsprit higher from the water, the sheer should be rather higher forward than aft, measuring the height from the upper water-line; and in the draught it should be formed to spring more close abaft the luff of the bow than at any other part, which, owing to the rounding of the bow, will appear, in perspective, when the ship is built, to be fair, though it may not look so well in the draught, in consequence of the draught exhibiting no perspective view. The decks should be the same height from the upper water-line forward, as they are aft, and hang not quite so much as the sheer. Projecting bows and raking sterns will make a ship the more uneasy in the pitching motions, and often dangerous in a sea. The stem above water should be nearly upright, when the ship is in sailing trim, and the figure-head and head rails project forward as little as possible. The counter and stern should overhang the buttock no more than absolutely needful; the counter with no more projection aft than may be requisite for the rudder case; it should also lay uprightly and have no hollow, in order to ease the shocks of the sea against it, which often operate violently and dangerously, when the counter is hollow and lays flatly. The upper, or second counter, should be at an easy angle; and the stern above, rake but as little as possible, merely enough to take off a stiff upright appearance.

SECTION II.

ON DESIGNING THE DRAUGHT OF A SHIP, CONTINUED.

Forming the midship bend.—Length of floor considered.—Form of the upper water-line.—Direction of the diagonal lines on the body plan: their form on the floor plan.—Height of greatest breadth.—Form of the main and top breadth ribband lines.—Correcting the rough draught.—Making a block, or solid model of the ship, from the draught, in order to rectify any further inaccuracies in the lines.—Designing the diagonal ribband lines.—The advantages of having recourse to making a block, with a view of finishing the draught correctly, illustrated.

102.—The expanse, or magnitude of the area of the immerged part of the midship bend, is a consideration of the first importance, with a view to enable a ship to pass through the water with the greatest facility, since the resistance will always be in proportion to

the magnitude, or extent of this area, let the form of the fore-body or that of the after-body of a ship be what it may: (see art. 13, 17, and 31.) The midship bend must necessarily be of such fulness, or expanse, as to conduce to proper capacity, and of such a form as to afford stiffness to the ship, and also of such form as will resist the rolling motion; but any fulness in it, or enlargement below water, more than is absolutely needful for due capacity, and to afford stiffness and resist rolling, ought to be studiously avoided in all ships intended for fast sailing. The proper form of the midship bend, usually called dead flat, has already been fully pointed out, (see art. 94,) and need not be recapitulated. It may, however, be proper to observe in this place, that the floor timber, at the next frame afore dead flat, should be nearly of the same rising as that at dead flat, that when the ship happens to heel on the ground, she may have sufficient length of floor, or of bearings, to rest on several timbers at the bulge at one time, and not bear on one only, because that one might be in danger of breaking from excessive pressure on it. But the floor timber, at the frame next abaft dead flat, should have a greater rising than that at dead flat; as much more rise as may be sufficient to prevent the body there, from offering any resistance to the water after passing dead flat, when the ship is swimming by the stern.

103.—In delineating the lines on the floor plan, the upper water-line, or intended line of floatation, or the line which the ship will swim down to when in sailing trim, demands especial care. To this, attention has already been drawn, (see art. 55 and 98:) it should present a long line of bearing, or have a long continuation of a good breadth, in a fair curve, from the midships to the luff of the bow; and also, from the midships toward the quarter, in order to afford a spacious and a firm support to the ship in all her motions. It should turn rather quickly at the luff of the bow, and continue on forward with a small curve, and become near the stem quite straight, but not to be in the least hollow: (see art. 40.) It should also turn quickly at the quarter, or at the termination of the line of bearing aft, and continue with a fulness till it approaches near the stern-post, and there terminate straight. This fulness aft, in the upper water-line, will be of advantage in giving to the diagonal lines below, which intersect it under the buttock, the best form to enable the water to restore itself to a level, and to fly clear off without obstruction, and thereby lessen the suction, (see art. 30;) it will also enlarge the capacity, and afford more support to the stern. The upper water-line should be the first line laid down on the floor plan, since some of the diagonal lines below will intersect it under the buttock, as will those also at the bow, and at such intersections they must necessarily be governed unalterably by the water-line.

104.—Those diagonal lines in the body plan which are, in the first instance, to be delineated as temporary ones, only, with a view

to ascertain the proper form of body that will ease the resistance and lessen the suction, should all of them, as near as possible, take that flight or direction which the water would naturally assume in being divided by the fore-body, and in its closing on the after-body. The water will always assume that direction which the form of the body imparts to it. If a broad thin board, like a spiling staff, is bent in a diagonal position on the bow, or in a similar direction to the ribbands, the direction which the board might take without confining the edges, or penning it, would be the same direction as the water would assume in being divided at that part; and the same observation applies in respect to the direction of the water, in its impinging and closing along the after-body. Such then should be the direction of these diagonal lines on the body plan. Although this direction may deviate from that of the ribband lines, yet the station of these temporary diagonal lines at the midship bend should be exactly where the ribbands are to be, or precisely at the surmarks; namely, at the floor, first and second futtock surmarks: and for a guide, another diagonal line will be needful lower down, in addition to these, drawn at halfway between the floor surmark and the keel.

105.—These temporary diagonal lines must necessarily be formed on the floor plan, with such curving, that the ship may have sufficient capacity; and be also formed so that the bulk of water displaced by the fore-body, and that displaced by the after-body, may be in due proportion to each other: (see art. 94.) In designing these lines forward, in the floor plan, the bulk of the body should be expanded most where the least resistance will arise from such expansion; and contracted in a corresponding degree, where any fulness might occasion the most resistance. And in designing these diagonal lines in the after-body, a greater fulness should be given to those parts, where such fulness would create the least suction; and a corresponding straightness in those parts where any fulness might occasion a material obstruction or impediment to the closing fluid. These may be considered so far, as general governing precautions in respect to these temporary diagonal lines.

The proper form of these lines, with a view to cause the least resistance, and to create the smallest suction, has already been illustrated, (see art. 20 and 30;) and which form should be adhered to as near as the contour or figure of a ship will admit; and, in addition, it may be proper to observe, that in delineating the lines from midship, aft, care should be taken that the body low down (particularly below the floor-heads,) does not catch the water after it has passed dead flat: the diagonal and perpendicular lines down below (especially under the flat of the floor,) should turn rather quickly from the midship bend, aft, to obviate such obstruction. In delineating the lines higher up, it will be needful to bear in mind, that their station is unalterably confined at where either

of them happen to intersect the upper water-line; and also to keep in view the spreading out of the body, from below to above the plane of floatation, since that is an indispensable object to insure to the ship due stiffness; and the form of timber in the body plan, to acquire due stiffness, must be preserved in the most ample degree, even though the resistance and the suction should be increased by the measure.

The height of the upper water-line being set off on the timbers in the body plan, the height of the greatest breadth, and the form of the timbers up to that breadth, can then be ascertained: for it should be remembered, the breadth hitherto assigned, is the breadth at the upper water-line or plane of floatation; and that the greatest breadth of the ship will every where be above the upper water-line in consequence of the body spreading out above water. The height of the greatest breadth will every where be at the spot where the water reaches up to on the lee side of the ship when she inclines the most under sail: (see art. 94.) Large ships heel from about seven to ten degrees; smaller ones, from seven to fifteen degrees; and some, more than this. And the line of the timbers, in the body plan, should spread out above the water-line up to this height of greatest breadth, at least as much as will cause the line of the timbers to be perpendicular on the windward side at the time the ship inclines the most under her sails; and even if it can be made to spread out more than this, so that it will but come in fair above, it will be all the better. The line of the top-timber can then be continued up, in the body plan, to form a sightly tumble home: (see art. 94.) And the main, and the top breadth ribbands in the sheer plan, and on the floor plan, may then be drawn off. The stern ought not to be too wide; the main and top breadth ribband lines on the floor plan should narrow, or clip in abaft, or round rather quickly at the quarters, from where the length of bearing terminates, particularly the main breadth ribband: and the quarter galleries should be as compact and as snug as possible so as to hold but little wind. The bow should be rather fuller at the main breadth harpen than at the upper water-line to afford support in pitching; and the top breadth harpen rather fuller than the main breadth: not, however, so much so as to cause the bow to be flaring, but only enough to make the topside upright at the luff, and to prevent its tumbling home there as it may do in midships.

The rough draught of the ship being sketched, it will then be needful, with a view to correct it, to compute the displacement of the ship, (see art. 84,) and also as near as possible the weight she will have to carry, and her own weight; and then to ascertain, how much the weight of water which she displaces, when down to her intended line of floatation, or when in sailing trim, corresponds with her own weight together with the weight she has to carry. If they should not happen to correspond, the bulk of the body below water must either be enlarged or else contracted, as may be requi-

site, in order that the water-line may be kept at the precise height determined on; or that the ship may draw neither more nor less water when ready for sea than described by that water-line in the draught, as her intended line of floatation when in sailing trim. With this view, the midship bend must be formed with either a little more or a little less rising at the floor; and the temporary diagonal lines, on the floor plan, must, in due proportion forward and aft, either be expanded or contracted a little to meet the difference; and the timbers in the body plan be altered; and the rough draught corrected in any other part accordingly. Ships of war ought to possess such a degree of stiffness from their form of construction, that when stowed with the utmost of what they are obliged to take, and the centre of gravity is therewith brought to the proper height, (see art. 95,) they should be enabled to carry sufficient sail with such weight alone, without requiring any ballast. And their capacity should be precisely such, that the utmost of what they may have, at any time, to take on board, might, in weight, be sufficient to bring them down to their proper bearings, or intended line of floatation, without any ballast being required: (see art. 83.) The weight of their stores, guns and ammunition, provisions and water, and of all other articles indispensably requisite for them to carry to sea, should, when they are equipped for a long voyage, always bring them precisely to that depth in the water designed by the draught for them to swim down to when in sailing trim; no ballast or superfluous weight should be required to bring them to it, to be so equipped: and as articles on board are used up, or consumed on the voyage, only that weight of sea water or ballast should, from time to time, be introduced into a ship, but such as might prove sufficient to preserve her original, or precise draft of water, and keep her in sailing trim.

106.—The rough draught being so far rectified, it will be proper to make a block, or solid model of the ship, exactly on the same scale as that by which the draught is drawn. A piece of light wood, such as pencil cedar or yellow pine, perfectly dry and well seasoned, and free from knots and shakes, should be prepared, of the requisite length, breadth, and depth, and be planed square and smooth. Three small holes should be bored through it lengthways from end to end, so as to admit three small iron rods, or stiff wires, to pass easily through them, but not loosely. One hole should be bored between the middle line and the side of the block, and at one-fourth down from the upper part of it; another hole to correspond to this, on the opposite side of the middle line; and the other hole should be bored through the middle line, at one-third up from the lower part of the block; and all must be bored exactly parallel to each other. When this is done, the exact station of every frame timber fore and aft must be set off on each side of the block; and then the keel, stem, stern-post, counter, stern, the middle line fore and aft, and the sheer, must all be correctly marked off upon it

according to the draught. This block should then be divided crossways into pieces or slices; it should with a fine set thin saw, be sawn through square athwarthship-ways exactly at where the station of every frame timber is marked off. The form of the timber, at the fore side, and at the after side of each slice, should then be scribed in on the two sides of each slice, from a thin paste-board mould, made exactly to the form of the timbers on the body plan of the draught: and the height of the sheer, and the breadth and depth of the keel, must also be drawn upon each side of all the slices. After which, each slice should be carefully pared or cut to the shape thus scribed or marked out. This being done, and the foremost and aftermost pieces fashioned and cut to their proper shape also, all the slices should be put together again in their original places on the three rods before-mentioned, and kept evenly, closely, and firmly together. The block will then present the exact figure in miniature of what the ship would be if built according to the rough draught.

The height of the upper water-line must then be set off on the block, at each frame timber, and on the stem and stern-post, and the line be scribed in all round on both sides of the block; and the height of the greatest breadth all along the line of bearing must also be set off from the draught and be *spotted in* on the block. The block should then be floated in the water; and by means of leaden weights be made to swim with the upper water-line, exactly even with the surface of the water all round. A stick to represent a mast should then be fixed into it, in midships; and by means of a string fastened to the upper end of the stick, the block should be inclined, or heeled on one side, as much as the ship would heel when under sail; and the line then described by the surface of the water at the lee side of the block (or the side it reclines on,) must be accurately marked off.

The block then being taken out of the water, it will be needful to examine at what places the height of the greatest breadth of the block, all along the line of bearing which was before spotted in, happens not to correspond with the height of the surface of the water, or of the line marked off at the lee side of the block when it was inclined in the water: and the draught must be corrected, and the greatest breadth made to correspond with the height of the line so marked off. It will then be requisite to make various other observations by a minute examination at every part of the block. To see if the form of any part of the bottom can be improved to please the eye, and still retain the essential advantages as designed by the draught; and, also, if the bow, or the stern, or the form and tumble home, and lines of the upperworks, can be improved in point of symmetry without prejudice in any respect; and if the sheer requires to be lifted or lowered at any particular parts to make it look fairer. In all which instances the rough draught must be rectified, notwithstanding such alterations may not in the draught

appear to be improvements, for the eye now becomes the grand reconciler in forming lines of beauty, from a view of the form of the body as it really will appear when the ship is built, since the form of the ship may now be examined in every point of view, with justness and perfect accuracy: and a more correct judgment of what pleases the eye can be formed by viewing a block, than by looking at a draught, because a draught exhibits no perspective, and affords but few points of view: the advantage to be derived from making a block, must, therefore, be obvious; at any rate, it will be soon manifested.

All the lines in the draught being thus improved, the lines down below to describe the diagonal ribbands which are actually used in the building of the ship, can then be drawn off in the body plan and on the floor plan; and by carefully inspecting the block, the judgment will be assisted in this respect in determining their flight or direction diagonally, so as to render their position more suitable for bringing on the strakes of the bottom, without prejudice to the proper security of the heads and heels of the timbers, and to their being kept steadily in their places by the ribbands, until the planks are brought on. And in determining the most advantageous canting of the timbers in the fore-body, and that of the cant timbers in the after-body, as well as of the cant of the fashion pieces, and of the lower transoms, the judgment will be no less aided by a careful and proper inspection of the block: it will be found to be an excellent guide in these respects, as well as being so important in perfecting the lines. Those only, who having designed a draught of a ship on true scientific principles, and who have afterwards subjected it to the test of a block, can only duly appreciate the many advantages emanating from the expedient; and it is advisable always to have recourse to this test, especially when a ship of any consequence is to be built; for, though the experience and abilities of the professional man be ever so great and eminent, he will in the final adjustment and finishing of a draught of a ship, find advantages to accrue from the making of a block.

SECTION III.

ON THE RUDDER OF A SHIP.

The great importance of the rudder.—On what its efficacy is dependant.—Its operation.—Much attention requisite in its use and management.—The proper form of, and best mode of hanging it, pointed out.—Observations on the angle presented by the rudder to the water.—The best angle defined, and in what manner it should be made available for practical use.

107.—Ships are often in such predicaments, that their safety absolutely depends upon answering their helm truly; and in all

their manœuvres it is of the utmost consequence that they should be under the command of their rudder. Still, however, highly important and indispensable, this curious and interesting appendage to a ship may be of, to her safety, yet, with unskilful management, it tends also to her destruction.

In order that the rudder may have efficient power to guide a ship, there must be a proper distance between it and the axis of rotation; and the rudder must have a sufficient breadth, and be made so as to go over to an adequate angle. The after-body of the ship must also have such a form as will admit of a free passage for the closing water, in its influx, to impinge against the rudder. Nor must the rudder be in the least enveloped with deadwater, to obstruct the force of the closing water against it, which sometimes occurs even when a ship has a clean run: as for instance, when a fulness of buttock happens casually to be brought down, but a few inches into the water, it will occasion deadwater there, and the operation of such deadwater to extend as an eddy to some depth below; and often to that degree and with such effect as to spoil a ship's steering. There must ever be a sufficient force from the water against the rudder or it cannot produce proper effect. This is obvious when ships are steering in a strong tideway, as also when they get into shoal water, or smell the ground. It is evident, also, in working to windward, they are then very apt to miss stays in consequence of the imperfect operation of the rudder; and, when coming about, are commonly obliged to have sails at command, to aid the action of the rudder, or the feeble effect of the closing water against it.

When a ship is sailing to windward, the water acts with greater force on the lee side of the rudder, owing to the pressure against that side of it by her lee way; and, consequently, operates with so much the less force on the weather side of the rudder, owing to that side of it receding from the action of the water by the drifting to leeward: and the heeling of the ship, in a measure, lessens its force on both sides of the rudder, because the surface of its sides then present a more slanting position. Although the power of the rudder increases with its distance from the axis of rotation, yet short ships have the advantage of coming about quicker than long ships: they, however, rarely forereach so far, seldom having so much vis insita force as long ships have. The force of the water against a rudder has a tendency to check a ship's headway; and more and more so, the further the helm is put over: it ought, therefore, never to be put over more than is absolutely requisite; nor even to be used at all but when necessary, or when attended with some advantage. In going before the wind, very little helm is ever requisite. When going to windward, its operation may then become advantageous, for a weather helm hugs a ship up to windward; but still only a small helm should, in this instance, be used, since the force of the water on the lee side of the rudder

is increased by the pressure of the lee way: a little more, or a little less of it, will, in this respect, in a measure, depend on the form of the bow, ships with sharp bows requiring more weather helm than those having full bows.

In putting a ship about, that is plying to windward, much nicety is required in the management of the helm: if she carries a weather helm, merely the bringing it in midships will cause the rotary motion to commence; and at this interval (in consequence of the rudder being then amidships,) it does not check her headway, or lessen the vis insita force; but if the helm is put down hard a-lee all at once, it will needlessly consume the vis insita force during this interval. It should also be remembered, that the force of the water against the rudder varies and lessens every instant, whilst, and as the ship is veering round; and this in the proportion as she gradually loses her headway: it is lessened also by the rotary motion causing the weather side of the rudder to recede from the action of the water; and this will be in proportion to the celerity of her motion in coming round. Consequently, the helm should be put down slowly, that it may neither check the headway of the ship, nor diminish the power of the rudder but as little as possible; and at the same time be put down with that due gradation, as to operate ultimately and effectually in bringing her about, affording her in meanwhile the utmost time for forereaching, particularly at the interval while in the wind's eye. The usual assistance of sails at this juncture, if braced in a position not to impede the ship's headway, is of material service, not only in bringing her head round, but also in preserving the vis insita force, which would in a greater degree be consumed by the additional action of the rudder that would, without the aid of sails be required. And it should be remembered, when using sails for this purpose, that those sails which stand the farthest from the axis of rotation, operate with the strongest effect in affording this aid.

108.—The rudder should be much wider at the lower part, and at the middle, than at the hance; by which the upper part will be less affected by shocks from the waves. And as the water always has the clearest passage to, and operates with the most force at and toward the lower part of it, it is both desirable and advantageous to have the greatest breadth of the rudder at and below the middle; and the heel of it should not run down so far as the under part of the main keel, but be four inches above it. The back of the rudder should be perpendicular, at the time the ship is in sailing trim; and it should be thinned at the after part to half the thickness of the main piece, and the back of it be rounded off, which will lessen the suction behind it. The bearding should not be trimmed to a sharp edge, but a substance of wood left to correspond with the rounding of the pintles. The rudder ought always to be heavy enough to sink down, and to rest with a good weight on the braces; and this weight should be contrived to be borne equally by two of the

braces. The second pintle up from the heel, and the one next above the upper or loaded water-line, should be dumb pintles, resting on cleats, or working in sockets, since, when the whole weight happens to be suspended above the water on one pintle only, the rudder when getting a little loose, or worn in the pintles, is liable to have an uneasy, noisy, tremulous motion, occasioned by the agitation of the water against it below. But when it bears on two pintles, its weight will, in consequence of resting equably at two distant places, keep it steady and quiet both above and below, and always prevent such an annoying disturbance. The stern-post, as mentioned in a former article, should have as little rake as possible: this will increase the length of deadwood below, and place the rudder the further from the axis of rotation; it will also form or produce a clearer passage for the water to the rudder, by which its force against it will be increased.

109.—The angle, which a rudder ought to make when the helm is put over, so as to produce the strongest effect in bringing a ship about, will depend upon the form of her after-body, as it relates to its fulness or cleanness; and, in such respect, it should be remembered, that the after-body is always cleaner below than it is above; and that owing to this irregularity of form, the closing water impinges in a different direction on the rudder at almost every different depth, while the side of the rudder presents but one position everywhere. Consequently, the force of the water against the rudder will vary at every depth, according to the direction at which the closing water impinges against it; and, therefore, it can only be at that part of the rudder, where the water happens to impinge against it at the proper angle, that it can strike it with the fullest effect. And hence a difficulty arises in scientifically determining to how much the rudder of any particular ship should be put over, in order to produce the best average effect.

It will be proper to investigate this point clearly and minutely. It is evident, that when the helm is amidships, (or the rudder fore and aft,) the water can have no force against the rudder to turn the ship one way or the other; neither, if the rudder could be placed right athwart, would the water have much effect in turning the ship; but its operation against the rudder would then be to stop her headway. It is, therefore, obvious, that there must be a medium position between these two extremes, or an intermediate angle, at the which, if the rudder was placed, the water would impinge against it with the most effectual force to bring the ship round. But even were the rudder to be placed in this most advantageous position, or angle, as it relates to any particular depth, the direction of the water against it, as has just been observed, will vary at every different depth, owing to the multifarious diversity in the direction of the taper of the lines in the after-body. The position of the rudder that would be most suitable at the buttock, would not prove fully efficacious at the keel: a less helm being

more suitable to the form of that part of the after-body, which is near the surface of the water, owing to its fulness there; and a greater helm more suitable to the form of the body below, owing to its cleanness low down. Thus, the best angle for a rudder to make, can with difficulty be ascertained in a scientific way: and this not only on account of the diversity in the directions of the lines of the after-body, but for another reason also; namely, because the direction of water, and its force, when passing along *curved* surfaces, to strike against a plane obliquely, is at present very imperfectly known, even at any given angle. In working a ship, a good helmsman would soon ken, what helm she requires; or which is the most efficacious position that the rudder should present to the closing water to bring her about; and, as in such respect, sufficient light is not at present to be derived from science, experience and practice must necessarily continue to be the guide, and every facility should be afforded with that view.

110.—The rudder, therefore, should be contrived so that the helm may always be put over sufficiently for it to present the most efficacious position, or form the best angle for tacking. In order to explain familiarly how this may be done; from a point, draw a line to represent a fore and aft line; and from the same point draw another line square from it, to represent a thwartship-line: then open the compasses to the breadth of the rudder, and fix one end of them at this point; and with the other end, describe a quarter of a circle, from one line to the other. This quarter of a circle will be ninety degrees, since a whole circle comprises three hundred and sixty degrees. Suppose now the fore and aft line, aforesaid, to represent the rudder, when amidships; and the line to pass through its middle fore and aft-ways; and the point before mentioned, to be the centre of the pintles at the fore part of the rudder. Then, if the after part of the rudder is brought round forward on this quarter of a circle, till the centre, or middle of the back, comes to fifty-four and a half degrees from where it was, when in its midship position, it is known that the rudder would then be at the precise angle for the water to strike against it with the strongest effect to turn a ship about; that is, however, to say, supposing the water was everywhere to strike the rudder exactly in a fore and aft direction, as it does at the keel.

But higher up on the body, owing to the fulness of the after-body there, the water would strike the rudder more in a thwartship direction; and in order that it might strike it there at an angle of fifty-four and a half degrees, the rudder would not require to be brought round more than, perhaps, thirty-five degrees from its midship position, in order to allow the water to strike against it at that part with the strongest effect, and probably less than that. Hence, it is reasonable to conclude, as is indeed found to be the case from experience, that a medium angle, between what is adequate below, and what is adequate above, must answer best, and

that such should be adopted. Therefore, if the bearding of the rudder is trimmed, so as to admit the rudder to be brought round to forty-eight degrees from the midship position, that angle will be nearly the intermediate one between what is required to produce the fullest effect at the keel, and what is required to produce the fullest effect near the water-line. And which will be found to answer every purpose, and prove quite sufficient for the rudders of all ships, of every different form of after-body; and to afford an ample scope to operate upon in steering; the attentive helmsman always bearing in mind, that putting the helm over too far produces the same effect as not putting it over far enough; namely, that it abates the power of the rudder.

SECTION IV.

ON THE MASTS OF VESSELS.

Their station in three-masted vessels considered, as it relates to the sails; and as in regard to the steering, and to the management of a ship; and in respect to the form of her body.—Where their station is best to be adjusted.—Their proper station pointed out.—Remarks on the rake of masts; where most properly to be set off from; and the most desirable rake defined.—Brief observations on the station, and rake of the masts of two-masted vessels, and of that of cutters.—Observations.

111.—The shifting of a mast a little more forward, or a little more aft; or the raking of a mast a little more or less; has often been observed to make a difference in the sailing, and in the behaviour of a vessel: and in this, experience proves what is but reasonable to suppose, that some judgment and circumspection is required in masting a ship properly; and which, on investigating the subject, will evidently appear to be the case. When a ship is under sail, the surface of all the sails that are set have a common centre, focus, or point of action, at which point their united forces are collected and evenly balanced: the force on the area of the surface of the sails that are spread afore this point, being precisely equal to the force on that which is spread abaft it; and that on those spread above this point being precisely equal to that on those spread below it. This is called the point velique, or the centre of the pressure of the wind upon the surface of all the sails that may happen, at any time, to be set on board a ship at once. The situation of this point must, of course, be at some certain intermediate distance between the fore and after end of a ship; and at some particular elevation above the axis of inclination. The higher it is situated, the greater will be the power of the wind on the sails to heel the ship: and were this point situated either afore or abaft a perpendicular with the axis of rotation, the head of the ship would veer one way or other according as the force predominated.

But in sailing to windward, this point must necessarily be situated more forward than the axis of rotation, (see art. 79,) so as to afford a greater press of sails forward, to counteract the augmented resistance of the water against the lee bow. Hence, the station of the masts require attention, in this respect, in order to produce a proper spread of canvas afore and abaft this axis.

The masts should also be stationed, so as to afford generally as large a spread of sails between them as possible: if placed well apart, the yards can be longer, and the sails squarer; there will also be more room to work them. And there is, besides, an advantage in manœuvering a ship, when the masts are spaced well apart; for if the foremast can be kept well forward, and the mizen-mast well aft, the sails on these two masts will then become at a greater distance from the axis of rotation, and thereby acquire more power in aiding the action of the rudder in bringing the ship about.

But the station of the masts may not only require to be regulated according as the sails, the steering, and the management of a ship may make it appear advisable, but also in a measure, according as the form of the body of a ship may render expedient. As, for instance, when the capacity of the fore-body, and that of the after-body, do not happen to be in due proportion to each other, the station of the masts, must, in a degree, conform to such disproportion. And again, if the bow is very sharp, and the stem below nearly upright, and there is a large gripe, the foremast will, in consequence of such circumstances, require to be placed further forward: for, although the ship might pitch violently, from the foremast being placed so far forward, and from her having so little fulness at the bow to support her when plunging, yet, her sails must necessarily be sufficiently forward to assist in counteracting her griping. On the other hand, if the bow was only moderately sharp, and the stem had a little rake below, and the gripe was not so large, the foremast would not then require to be so far forward, and of course the ship would plunge the easier in a sea. The situation of the masts being therefore in a measure dependant on the form of a ship, no general rule for their station can be given, that could apply correctly to all ships, for there would of course be such varieties in the form and proportion of ships, as to occasion a deviation from any general rule absolutely necessary, and peculiarities would also often present themselves of a nature to require especial attention.

112.—The plane of floatation being the seat of a ship's motion, and upon which all the operation of her sails are communicated; and the situation, and in a measure, the spread of the sails depending upon the station of the masts, their station should therefore be set off on that plane, it being there where they are most properly and adequately to be ascertained and adjusted; namely, at the plane of floatation of the ship, or in other words, at her intended line of floatation, or at the line described by the surface of the water when she is in sailing trim. If the fore-body and the after-body of a ship

are in due proportion to each other, it is then advisable to place the foremast at the same distance aft from the stem, as the mizen-mast is placed forward from the stern-post. The most proper distance, in this respect, is one-seventh part of the length of the ship: this length is to be taken on the sheer plan of the draught, from the after part of the stem to the fore part of the stern-post, at the height of, and along the above-mentioned water-line, or plane of floatation, setting off for the station of the foremast on the plane of floatation, one-seventh part of this length from the after part of the stem, at where it bisects this plane; and for the station of the mizen-mast on the plane of floatation, one-seventh of this length, from the fore part of the stern-post at where it bisects this plane. This station for the mizen-mast on the plane of floatation, will prove suitable for most ships; and rarely require to be different in any. If the bow of a ship is very full, it will be found expedient to have the foremast rather more aft; its station at the plane of floatation should then be at about one-sixth part of the length of the ship before mentioned, measuring aft from the stem at where the stem bisects this plane. The station of the foremast, and that of the mizen-mast at the plane of floatation, being once determined on, the station of the mainmast can then be properly ascertained; and this by a rule that will apply to every ship. It is determined as follows: measure the exact distance from the centre of the foremast, to the centre of the mizen-mast, along the plane of floatation; and from the centre of the fore-mast, set off six-tenths of that distance aft, for the centre of the mainmast. And this will be the proper station on the plane of floatation, of the mainmast of any ship, as it relates to its distance from the other two masts, when the station of those two have been previously determined.

113.—There is much consideration also due to the raking of the masts aft, since material advantages emanate from that recourse: it gives the masts a play aft, against the pressure communicated on them by the sails; or it affords a degree of elastic resistance against the force of the wind on the sails, producing a peculiar beneficial effect. The force of the wind then operates as a lift to the over-hanging weight of the masts, in rearing them to a perpendicular, and in consequence has not so great an effect in elevating the stern, and in depressing the fore-body of the ship; and in causing so much of that additional resistance, and increase of suction arising therefrom, as would accrue, if the masts were upright, and no such elastic resistance interposed in the first instance against the force of the wind. There is also an advantage arising from the raking of one mast more than another; it increases the distance between them aloft, and gives more room for a wider spread of canvas between them; more room also for working the sails, and they fill the better for it. In order to acquire such advantage, the main-mast must rake aft rather more than theforemast; and the mizen-mast must rake rather more aft than the mainmast. The rake, how-

ever, in any instance, should be moderate; or it might throw too great a strain on the stays, when the bow rises on a high wave: it might also endanger the safety of the masts, were any accident to happen to the stays.

114.—The station of the masts of a ship, having for the reasons before adduced, been adjusted on the plane of floatation, or on the water-line, when she is in sailing trim, it is no less expedient to determine the rake of the masts from that plane also; since it exhibits the horizontal position of a ship, as she sits on the water when in sailing trim; and it is therefore proper, that the rake of the masts should be set off from a perpendicular drawn up from this horizontal line of position, rather than from the straight line of the rabbet of the keel, which latter, owing to the ship swimming by the stern, becomes out of a level when she is in sailing trim. The rake of the masts may be determined and delineated in the following manner. From the station of each of the masts on the plane of floatation, as already set off in the sheer plan, draw up a line perpendicular to this plane, (or square up from it,) and let the foremast rake aft an eighth of an inch to a foot, from the line so squared up; the mainmast rake aft, five-sixteenths of an inch to a foot; and the mizen-mast rake aft, half an inch to a foot from the line squared up. Such rake for each will be moderate, and yet enough; and the difference in the rake of each mast will sufficiently increase their distance apart from each other aloft.

115.—Two-masted vessels being rigged in a variety of ways, but few observations can be offered, in regard to the stationing of their masts, that can apply in a general way. It will, however, as it respects all descriptions of two-masted vessels, be proper to station their mainmast as far abaft the axis of rotation as circumstances will admit, in order to give the after sails more power in manœuvering; and with the same view, it will be proper to station the foremast as far forward as the form of the bow may render advisable for it to be placed: due regard however being had to the position of the point velique with the axis of rotation as before illustrated. The rake of the foremast, and that of the mainmast of two-masted vessels that are square rigged, should be much the same as that of the foremast and mainmast of ships, which has been shown in the preceding article, and the rake should be set off in the same manner; but the masts of two-masted vessels, that carry fore and aft sails only, should rake rather more than that.

116.—In stationing the mast of a cutter, especial regard must be had to the difference in her draught of water forward and aft, cutters usually swimming very much by the stern; always observing that the point velique should be rather afore the centre of lateral resistance, or the centre of the area which is presented by the bottom all afore and aft, from the keel to the water-line, when swimming by the stern, and in sailing trim: (see art. 73.). The length of the bowsprit; the station of the fore-stay at the stem; the

overhanging of the boom aft; the rake of the mast; the hoist of the sails; and draught of water: these being all known, and the centre of lateral resistance also ascertained. A sketch should then be drawn on the same scale as that of the draught of the cutter, and on it each of the sails should be delineated with such spread, and in such proportion to each other, as that the point velique, or centre of the surface of the three sails, may, when the cutter is in sailing trim, be a little afore the perpendicular, from the centre of lateral resistance. The spread, cut, proportion, and position of the sails being thus described on the sketch, the station of the mast will then be shown, by where the fore part of the mainsail comes, and may be correctly delineated in the draught. The rake of a cutter's mast aft, should be half an inch to a foot, set off from a line squared up from the plane of floatation, as has just been explained, in respect to the masts of ships.

When a vessel is swimming down to her intended line of floatation, with all her proper sails hoisted for sailing to windward, close hauled and well braced, if she should not then happen to carry a sufficient weather helm, her draught of water, or line of floatation, or of bearing, should on no account be in the least altered to make her do so, but other means ought to be resorted to. With this view, provided no prejudice is created, the rake of the mast might be altered; the raking of the masts a little more aft would make her carry more weather helm; since by that expedient the point velique and centre of effort is brought more aft. On the contrary, if she is found to carry too great a weather helm, the raking of the masts a little less would ease that defect.

SECTION V.

ON THE SAILS OF SHIPS.

The thwartship position of the sails to receive most wind.—In what instance a ship derives the most assistance from them.—Their vertical position, as it relates to elevating the body and easing the depression of the bow.—Force of wind; how abated on the sails, by a ship going before it; as also when the wind is on the beam; and when aslant.—Its effective force on sails when set obliquely to it: the angle assigned by the theory, as the most proper one, not satisfactory.—The cut of the sails; and their trim: difficulty in ascertaining the best angle for the sails to make with the wind.—Lee way; as depending on the construction of a ship; and on other causes: how best to ascertain the lee way, and to determine the best position of the sails, and the lay of the ship.—Practical remarks.

117.—Ships derive the most assistance from their canvas, when they are going with a flowing sail, and the wind is just far enough

abaft the beam, or upon the quarter, as to fill all the sails when trimmed, without screening the wind from each other. At such times also, as when the sails forward and those abaft are so duly proportioned, as to require but little helm to steady the ship's course, and the rudder, in consequence, offering no obstruction to her headway. The sails operate more effectively also, according as the vis insita force of a ship may happen to be sufficient to give uniformity to her onward motion, and steady the impulse of the wind upon them. And when also the sails, from their vertical position, tend rather to elevate than to depress the body of the ship in the water.

It has been observed, in another place, (see art. 42,) that the equilibrium of the upward pressure of the water, under a floating body, or under a ship, is always destroyed by progressive motion. By the force of the bow against it, the water is gorged up in its front, (see art. 12,) and it also diverges with an upward impulse under the body, (see art. 19,) which produce a tendency to make the ship rise a little higher in the water, and to diminish her area of resistance; causing the propelling power, in its efforts to overcome the direct resistance, to revert, in a measure, on the immersion of the ship; or, which is the same purport, causing the velocity produced by the propelling power, to lighten her pressure, or bearing on the water, tending thereby to lessen the draught of water; and this in proportion to the degree in which the resistance might happen thus to operate on the immersion, by the rising of the body and diminishing the area; or, to the degree in which it might prove easier for the propelling power to rise the body a little, than to stem the whole direct resistance when the obstruction happens to become less by the body partly lightening, or easing itself over the fluid, than by overcoming the whole of the direct resistance from the water. The lightening, or tendency of the body to rise in the water, produced by its velocity, equilibrates the resistance and the propelling power, and increases with the speed of a ship. The propensity to rise commences when she has attained a velocity exceeding that at which a heavy body dropped at the surface would fall in the water; or that at which the ship herself by falling could settle down in the water to her swimming mark. At such velocity through the water her body has a tendency to rise in it; and when this effect begins the resistance will increase in a smaller ratio with the increase of velocity afterwards acquired, in consequence of the body gradually rising and diminishing the area of resistance; and it would increase in a still smaller ratio, could the speed of a ship be sufficiently quickened, and the area of resistance still more diminished. The ratio of the increase of resistance with increase of velocity, in respect to floating bodies propelled at greater rapidity than ships move at, would continue to be smaller and smaller with increase of rapidity, until the velocity actually produced a terminal resistance, or until the resistance ceased to

increase with increase of velocity. And such body having attained that rapidity, if the propelling power was then to be increased, (and that perhaps not very much, provided the power continued to apply as closely or as quickly against the body as to keep pace with its velocity,) quite a different effect would be produced: the resistance then would diminish; and go on diminishing as the velocity increased, until the body became forced up so as merely to skim the surface, and the water resistance nearly ceased.

Thus, the speed of a ship, at every rate of velocity she may go at, after she has attained a velocity greater than that at which she can settle down, might, with the same propelling force, be quicker than it would be, supposing her velocity did not lighten her pressure on the water, or if the body had no tendency to rise in it. And hence, this tendency should be facilitated and the effect promoted; and, therefore, the power or force to give velocity to a ship, ought never to operate in a manner to depress the body in the water, or to counteract any tendency which it might have in rising to effect her passage the easier through it. Now the sails of a ship always operate against such tendency, in consequence of their elevation above the plane of floatation; and thus far the adoption of sails for propelling, or forcing a ship along, may be deemed objectionable, or at least, may be considered as not operating with so efficient and proper effect, as the same degree of power would do, if applied near the surface of the water, like the paddle wheels of a steam ship, or similar to the tow rope of a canal boat. Such disadvantage, in respect to sails, should therefore be lessened as much as circumstances will admit of. Hence, as the force of the wind on them tend to press down the bow, (particularly when a ship is going large,) it is not only advisable for the masts to rake aft, with a view to lessen this tendency, as has already been illustrated, (see art. 113,) but also that the lower part of the sails, particularly of those in midships and afore it, should stand more forward than the upper part, so as to flow up with the wind; similar to the position of a paper kite flying in the air, that the force of the wind by acting upwardly on the square sails, may tend to uplift the body of the ship rather than to cause such depression; and thereby aid such tendency to rise, or to lighten her pressure on the water, as may happen to accrue, or be consequent on her rate of velocity, by the which her speed might be increased, perhaps, half a knot or more: an advantage of no small import to a ship when she is in full chase. The light fly boats, that are towed by fleet horses, on canals, at the rate of ten miles an hour, experience very much greater relief in respect to their resistance and increase of velocity from rising in the water, than heavy ships can do; and that in proportion as the weight and resistance of the respective bodies bear to the propelling power at any given velocity beyond the speed at which such effect commences. Indeed, if ships under sail were to rise in the water so much as these canal boats, when

towed so swiftly along, it would endanger the safety of ships, by elevating their centre of gravity above their bearing in the water, and cause them to go on their beam ends.

With respect to steam ships, their speed might, in consequence of their propensity to rise in the water, be very much increased, provided the velocity of their paddles in plying against the water was regulated, so as to *keep pace* with the velocity of the ship, *as her speed might be increased.* The piston rod of the steam engine being limited to a maximum movement, cannot increase the velocity of the paddles beyond a certain rate. Moreover, by the velocity of the ship, the paddles recede from their action against the water, or their force in striking it is thereby abated: and the rotary motion of paddle wheels, as they are now arranged, being thus restricted, they cannot be sufficiently accelerated so as to produce a constant fulness of pressure, or effectiveness of force of the paddles against the water. The force of the paddles against the water is usually about one-seventh part of the amount of the power that is actually applied in propelling the ship, or of the power of the steam engine as produced by the cranks. They will be in proportion the one to the other, as the mean horizontal distance from the end of the crank to the centre of the paddle shaft, is, to the distance from the centre of the paddle shaft, to the middle of the immersed part of the paddles, precisely according to the law of the lever. Hence, a small abatement in the force of the paddles against the water, will make a great diminution in the propelling power, by their not affording to the steam engine a due counterpoising force. The rotary motion of paddle wheels, require, therefore, and should have *freedom of acceleration:* with this view, if there were only about three-fifths of the usual number of paddles round the breast of each paddle wheel; and the drift and spur wheels of the machinery were proportioned so that the paddle wheel might perform about double the number of revolutions per minute, to the number of strokes which the piston rod gave per minute; or as when the paddle wheels performed thirty-six revolutions in a minute, the piston rod might give but eighteen strokes, while its maximum movement might be, or it would give, twenty-eight strokes per minute, according as the velocity of the ship might render a quicker rotary movement of the paddle wheels needful: with such arrangement the speed of steam ships would prove to be much more rapid with the same steam engines, since it would enable their force, or power to follow up the velocity of ships, as their speed increased; and the number of the strokes of the piston rod be thereby reduced, less steam may be expended, and a smaller quantity of coals might be consumed; for it should be remembered, that whatever may be the number of the strokes of the piston rod less than its maximum movement, the propelling force will, in degree, be still the same: and it is the degree, or intensity of the force, that wholly constitutes its effectiveness in propelling a ship, since the quantum

of power produced, in any given time, by a steam engine, though of great importance in machinery, for manufacturing, operates with no such advantage as it relates to its application on board a ship. And further, if the paddles of steam ships were contrived as they frequently are, so as to be always perpendicular while in the water, they would be importantly preferable for the increasing rapidity of the rotary motion of the paddle wheels here suggested, and which rapidity is indispensable to producing the utmost speed to a ship: the paddles also by their being moved with greater rapidity, will avoid becoming a backwater while just even with and at a little below the surface of the water, which they now are.

118.—From the immediately preceding observations, it will naturally occur that *wind* must be a very precarious agent for propelling ships, since it often is rendered inadequate for the very same reason; namely, its whole force never keeps pace with the velocity of a ship: and here arises another material disadvantage attending the adoption of sails for forcing a ship through the water: this, however, in their use, cannot possibly be obviated. The force of the wind, in proportion to the velocity at which it blows, has already been adverted to: (see art. 2.) Its pressure on the sails of a ship, is always lessened by the velocity of the ship through the water, since the sails recede from the wind by the motion of the ship in going from it; and more or less so, as her course may happen to be either before or by the wind. In going before the wind, the sails can only be pressed against by the wind, with such a portion of its velocity (or force,) as may actually exceed the velocity of the ship through the water. If, for instance, the wind blew with a velocity of twenty-four miles an hour, and the ship went before it at the rate of six miles an hour, it is obvious, the wind could only press against the sails with a velocity of eighteen miles an hour, since the ship would at the same time be going from it at the rate of six knots; and the force of the wind on the sails, always diminishes in consequence of the sails thus receding from its impulse. When the wind blows sideways, or is upon the beam, its force on the sails is not then so much abated by the velocity of the ship, since the ship does not then move forward in the same direction to where the wind blows. And when a ship is close hauled to the wind, its impulse on the sails is still less diminished by her headway; for, her course is then, in a measure, as against the wind: the position of the sails being so oblique, and the direction of the ship's motion so near the wind's eye, that the sails can then recede but very little from it.

119.—The force of the wind on a sail, when placed obliquely to it, always operates in a direction at right angles with (or perpendicularly against) the surface of the sail: and this force is usually understood to diminish in the exact proportion as the position of the sails become nearer in a line with the direction of the wind; or as the theory expresses it, "in the ratio of the square of the

sine of the obliquity." But there is reason for doubting this; and to conjecture that the force of wind against a sail, when close hauled, may be greater than is assigned by the theory, for certainly in that position the sail does not recede so much from the wind by the motion of the ship; and it may be remarked also that when the bow of a ship is of that degree of sharpness, or when it strikes the water in the same oblique direction as the wind strikes a sail when close hauled, the resistance of the water against the bow, is, in that case, found by repeated experiments, to be more than double as much as what the theory give it: (see art. 18.) It is to be lamented, that the theory should, in so many instances, differ; and in some prove so enormously erroneous, when put to the test of experiment, since it is apt to create doubts as to its accuracy in other similar respects.

The sails of a ship are considered to be in the best position to the wind, when the angle of incidence is about twenty-three degrees; but if the theory was even correct, in this respect, much also would have to depend on the cut of the sails, whether they set well or not. If they happen to belly, or bouge out much in the middle, the wind might not impinge with any effect on the weather side of the sails, while it would catch the lee side of the sails with augmented force; and operate there in a direction to increase the leeway of a ship, rather than to promote her headway. The sails sometimes used by those ancient, ingenious, experienced people, the Chinese, are, in this respect, much superior to ours; for their sails are rendered stiff, and flat as boards, by bamboo stretched across and attached to them. Sails, in order to answer most effectively when close hauled, should present to the impulse of the wind, as straight, or as flat a surface as possible. And in plying to windward, all the sails should be sharp braced, and in the same oblique position, or be trimmed properly: a ship will then often move ahead at an extraordinary rate, and with a surprising proportionate speed, compared to the velocity at which the wind blows, seemingly as though the force on the sails was increased by the ship's moving toward, or against the wind; but this can only be to appearance, and not in reality. Some part of the swifts of a windmill may, however, be often observed to move actually faster than the wind blows, and doubtless does so: the rotary motion being quicker at the outer end than at the middle of the sails, the power of the wind may, in consequence, cease at the outer end; and the sails there are often seen flapping in the wind, while its power is at the same juncture operating with full force and effect at the middle of the swifts to drive them round. Ships usually lay from five and a half to seven points from the wind, some more, some less; few can make much way if they lay nearer than six: there is, however, much variation in respect to their laying to the wind. This arises from the difference in their built; from the manner in which they are rigged; and some ships' yards can be braced about

sharper than others, from other causes as well: incidents also occur, in practice, while manœuvring, oftentimes apparently unaccountable, and certainly not to be foreknown. Hence, the most advantageous position for any ship to lay to the wind, cannot be accurately calculated upon by the man of science; not only for these reasons, but also because the theory cannot be satisfactorily relied upon in such respect; and it is, therefore, better to ascertain the best position that any ship ought to lay to the wind, by trial, rather than depend upon any calculations for government in such respect.

120.—Long ships having more lateral resistance, they, in consequence, make less lee-way than short ones. If a ship four times as long as she is broad, should, in going four miles ahead, make one mile lee-way, she would, if only three times as long as broad, (all things else being alike,) make the mile lee-way, while going only three miles ahead. Ships also that draw much water, having, in consequence, more lateral resistance, they, of course, make less lee-way, than those that draw but little water. And in respect to a ship's being weatherly, that will depend also upon her form, and upon the degree of obliquity of the surface presented for lateral resistance by the curves of her body: (see art. 75.) It will also depend upon her degree of stiffness, or uprightness under sail: (see art. 94.) And upon circumstances also, not always to be calculated. The lee-way any ship may be liable to make is soon discovered, when working them to windward, and can always be ascertained by practice, at least, more accurately than it can be computed scientifically: many circumstances present themselves in manœuvring a ship, which cannot be foreknown and brought into calculation: incidents often occur, even trifling ones, greatly affecting the behaviour of a ship under canvas, that baffle all computations. After a little trial and experience in manœuvring a ship, her qualities and capabilities in these respects, may be pretty well known; and then it will be easy to ascertain correctly, at any time, when the course of the ship, and the direction of the wind is brought under consideration, what would be the most advantageous position or lay of the ship, and the best position of her sails, with a view to run upon the contemplated course with the greatest expedition.

When a ship is chasing another to windward, the chasing ship ought to tack as often as she brings the chase on her beam. And when a ship is chasing another that is to leeward of her, the chasing ship ought to keep the chase always on the same point of the compass, that she was on when first seen. In some parts of the ocean, heavy long swells, perhaps a furlong in length, or more, are very common: a ship in descending such lofty long waves, obtains an accelerated motion, similar to that accruing to a heavy body, when descending an inclined plane. She then acquires an augmented velocity, a degree of speed over and above, and totally distinct and independent of that which is produced by the force of the wind on her sails. And here the vigilant steersman will watch opportuni-

ties of advantage, to improve the position of the ship toward, and to facilitate her progress to the object in pursuit, and yaw a little, at such times, while of her own accord the ship is rushing furiously down the slope.

SECTION VI.

ON THE TRIM OF SHIPS.

Observations.—Importance of ascertaining it, manifested.—Causes affecting it.—Illustrations in respect to the subsidence of the after-body.—The importance of ships being pliable, and the advantages pointed out.—Combining strength with pliability.—Facilitating pliability, by stowage, and by other similar measures.—The trim as affected by the sails; and also as affected by elasticity, in respect to the rigging, and the rake of the masts, and by other causes.

121.—Although a ship may be designed on the most correct scientific principles, with a view to sail well, and be built ever so carefully from the draught so designed, yet, the fairest expectations are often disappointed; the object defeated, not from any error in the form of the body, but it becomes a failure from other causes. It has frequently happened, even when two ships have been built from the same draught, and by the same moulds, and when equipped for sea, have been apparently alike in all respects, that one has sailed exceedingly well, and the other very badly. Indeed it has often been remarked, that the very same ship will sail much faster at some intervals than at others; and this, without any cause having been perceived to have occasioned such difference in her speed. These are circumstances that claim the most earnest attention, not only from men of science to endeavour to explain the causes, but also (as will be seen) from the practical ship-builder, with a view to obviate them by improvements in the putting a ship together. Nor, (as will be shown,) is less attention required from the nautical officer, in the management of a ship: to observe incidental operations, and to endeavour to find out, and then to keep what he calls the trim of the ship. The very fastest sailing ships, of which our enemies have ever been possessed, have been overtaken and captured by us, merely from the circumstance of their being put out of trim, by the means they have resorted to, and adopted to attempt escape. In one instance, a remarkable fast-sailing ship, that had flown from our fleetest frigates, being pursued by several of our ships at one time, attempted to get away by the injudicious recourse of lightening the ship, and by so doing, utterly spoiled her sailing; imagining that by lessening the weight of the ship, her speed might have been accelerated; and inasmuch as the area of resistance of the midship bend was lessened by so doing, there might have appeared to them some reason for her going faster: they were not,

however, aware of the consequences of the expediency, that by reducing the weight, they injured the line of bearing, and power of carrying sail, and lessened the vis insita force of the ship. Another extraordinary fast-sailing ship that had been cut out of a harbour by our boats, and instantly pursued by the enemy, would have been overtaken and re-captured, had not her trim been made known to our officers on board, by one of the seamen belonging to her crew. Circumstances apparently very curious, and in instances even trifling in their nature, have sometimes put a ship in and out of trim. But every incident may be scientifically traced, as either to relate to the pliability of the ship, in allowing her to yield to any partial pressure of the water, arising from the force of the wind on her sails, or else to relate to the position of her sails, or otherwise as to the degree of elasticity afforded by her masts and rigging, in the receiving and communicating the force of the wind upon them. These points it will therefore be needful to elucidate scientifically.

122.—By surveying the form of a ship, it will be readily seen, that the timbers of the after-body commence in a perpendicular direction upward from the keel; and above the deadwood, they will be observed to form a hollow, and a little higher to lead in a direction to rest flatly on the water, similar as the floor timbers rest on it in midships, on which flatness the after-body is seated upon the water, and there receives its support in an upward direction. Again, viewing the form fore and aft-ways, the after-body will be seen to rise or to slant gradually upward from the flat of the floor in midships, all along under the flatness of the after-body just described, up to the surface of the water at the buttock. And this slant, or oblique direction of the flight, of that part of the after-body which supports it, will be observed to deviate very considerably from a level. Now, the direction of the motion of the ship through the water, being precisely level, the after-body has, when the ship is going forward, a tendency to forsake the support of the water under it, in consequence of the ship moving in a level direction, and the support of the after-body laying in a slanting or sloping direction. By thus forsaking the water, the after-body is liable to dip, or to subside, owing to the loss of its support; or, as mariners term it, to sink after her tail: for as the support which every floating body receives from the water, is directly upward, consequently, whenever the velocity of the ship is such, that the water has not sufficient time to close up underneath, the after-body must inevitably subside, from the loss of its support: the after-body would be forced down to a bearing, by the gravitation of its own weight, as well as by the downward pressure of the atmosphere upon the body above; since the upper part of the after-body being above water, it becomes subject to the whole pressure of the atmosphere upon it; and that operates in the prevention of any tendency to vacuum under those parts of the after-body that rests flatly on

the water, in the same degree as it would do in creating such tendency by its operation at the midship bend, supposing the ship was like a body in motion to be wholly immersed, and the water in such case had to close upward under the after-body without having sufficient time to do so.

The after-body, therefore, dips down, or subsides, upon losing any part of its support from the water, when the ship is in motion. But here observe, the after-body could not subside without the midship bend being in a measure more deeply immersed, for, on losing any of its support, it would bear down the midship bend, and the midship bend by being deeper immersed, would have a larger area for resistance, and of course cause greater resistance; and which increase of resistance must be precisely equal to the impediment from the suction, that would accrue from the tendency to vacuum, between the under part of the after-body and the water, if the pressure of the atmosphere upon the after-body, and the weight of the after-body itself did not keep it down in close contact with the water and prevent it. Hence, an impediment to the velocity of a ship arises from the midship bend being deeper immersed, when the after-body loses any of its support from the water and subsides. But if the after-body could, by any means be made to subside, without depressing the midship bend, this additional resistance would be obviated, and of course the velocity of the ship be improved.

123.—When a ship is so firmly put together as to become inflexible, the midship bend must always be deeper immersed whenever the after-body subsides, as illustrated in the immediately preceding article, because the one part cannot move without the other, she is bound fast, and becomes unyielding to the partial pressure attending the operations of her natural element. But if a ship was put together in such a manner as to be pliable, and to bend or yield a little in midships, so as to allow the after-body of its own accord to subside, without depressing and enlarging the midship bend, she would then escape the additional resistance, and of course go faster. The advantage emanating from pliability of construction, by enabling the after-body to subside, without depressing the midship bend, becomes therefore of material import, and claims more especially the attention of the practical ship-builder, in the putting of a ship together. It is in a very paramount degree, owing to the want of pliability, that so many failures and disappointments occur in the sailing of ships, as before alluded to; and why the fairest expectations of the ship-builder are so often defeated. Experience and observation has induced a common opinion, that pliability in the construction facilitates the sailing of ships; but it has rarely been attended to by the practical builder in the construction of ships, as its importance demands; nor has its operation in accelerating the velocity of a ship been rightly comprehended.

The advantage and expediency of pliability, is very evident in a

scientific point of view; and, experience has amply proved it, as occurring from the different manner in which ships have been constructed; this has been witnessed in many that have been built in America, and in other parts of the world, in which instances the advantages of pliability of construction has accidently manifested itself by their being badly built, and flimsily put together. When it has happened also to have been fortuitously thought of and resorted to in cases of emergency, its importance has frequently been experienced. Instances have been known when vessels have been pursued by an enemy, and extraordinary efforts required to be made in order to expedite their sailing, that the sides of the vessels have been cut down, (the planks in the upperworks sawn through) in midships, whereby their speed has been so much accelerated, as to have enabled them to effect their escape. The reason of this is very obvious, the vessels have thereby acquired pliability; and (though certainly a dangerous expedient,) a more effectual recourse to obtain pliability in midships, and to enable the after-body to subside, could not have been resorted to.

Nature also displays to us the necessity and importance of pliability, in the inimitable structure of the bodies of fish, with such a degree of pliability, as it must indeed be allowed, art can but very partially attain in the construction of ships. The flexibility of the tail; the suppleness and motion of the whole back bone, and their muscular parts, enable them to vary their form, and to yield to any partial pressure from the water that might otherwise obstruct their passage, and impede their velocity through it, while, by means of their air bladder, they dilate or contract their bodies at pleasure. And with all this admirable pliability, union of parts are preserved; and strength combined in a most wonderful and exquisite manner. But art can only imitate, and the most complex machinery which the genius of man was ever able to contrive or to conceive, sink infinitely beneath the lowest, the simplest portions of animal mechanism: the former is always susceptible of improvement, whereas that displayed in animal bodies is incapable of being altered for the better. But even if nature had not thus furnished evidence, that all bodies to move swiftly through water, must of necessity possess pliability, in order to ease the resistance of the fluid, and to lessen the suction, and enable them to attain their wonted velocity, still it would have appeared no less conspicuous and evident on scientific grounds.

Strength is doubtless one of the chief perfections of a ship, and requires the utmost care. But if pliability can be united in the construction, without diminishing strength, or endangering the safety of the ship, pliability must also be allowed to be a most desirable object, since it promotes another of the chief perfections of a ship, namely, her swiftness. In some of the materials used in their construction, strength and pliability are evidently combined: this is manifested in many trees, which enables such to bend and

yield to the blast, while those that are stubborn and inflexible, break : and the wood of those trees, although extremely pliable, is yet very close-grained, tougher and stronger than many of the hard brittle woods, and some of them almost as strong as any wood. In the building of a ship, that is intended for fast sailing, pliant tough materials should be introduced at those parts, which are most liable to strain, in yielding to partial pressures from the water, they are therefore especially desirable all along the midship parts, where the pliability of a ship hinges ; and no inflexible brittle wood should be introduced thereabouts, neither for timbers nor for plank. If the upperworks of a ship are lofty, they will yield less than if otherwise; low snug upperworks conduce to and afford most pliability, and they strain the least. The planks on the upperworks should be narrow and long ; narrow strakes and narrow butts are preferable with this view. Metal fastenings are infinitely better than treenails ; they will hold the planks firmer to the timbers, provided the points of the bolts are well and properly secured ; they also wound the timbers less, and do not then require them to be of so large a scantling. Nor should the ship be too rigidly bound by superfluous fastenings, especially in the upperworks, and the sheer strakes still more particularly. There should be sufficient fastenings at every part, to keep the planks firmly to the timbers, and to hold the ship securely together : more than that is not only unnecessary, but prejudicial. By adopting such means, and observing those precautions, a ship will acquire a sufficient degree, both of strength and pliability, and the practical ship-builder will experience no difficulty whatever in combining these two essential objects.

124.—Particular attention is also required from the officers of the ship in this respect, since the advantages derivable from pliability of construction, can be augmented in a very material degree, by stowing the weight on board in such a manner as not to operate against her pliability, but to facilitate, and to act in union with it, and thereby increase the effect in expediting the speed of the ship. This increase of effect will accrue when the weight of what the ship contains, is so disposed and stowed toward the midship parts, that the displacement of the water under the extremities of the vessel, may be rather greater than their specific weight requires for their respective support ; or, as though the fore-body and the after-body, suspended or supported a small portion of the weight stowed in the midships : (see art. 96.) From being thus stowed, the fore and after bodies would be forced up a little, by reason of their buoyancy being greater than their specific weight requires ; and the pliability in midships yielding to it, an additional and a lively portion of it would be acquired without straining the ship; and the pliability thus operating in a twofold degree, or both ways, upward as well as downward, would enable the after-body to subside by pliability, nearly double as much as it could do, if the additional facility accruing from stowage, had not been acquired.

Attention is required from the officers on board, in other respects also; namely, to see that nothing confines or restrains the pliability of a ship. Care should be taken, not to place any heavy articles at, or near to the bow and the stern: even the bringing of a few of the foremost guns toward midships have been known to improve sailing, and this, by its easing a weight where it had, in consequence of being so far distant from midships, so much greater power, in confining the pliability of the ship at the part where it hinges. Hence, during the time a ship is at sea on her voyage, the anchors being then of no utility, they should be moved from the bows to as near the midships as circumstances might admit of. There is very much to invite the observation of the intelligent officer: trifling circumstances, such as bowsing guns from the sides toward midships, have been found to produce a beneficial effect on a ship's sailing; and this has arisen from its having removed a restraint on the pliability of the sides. Ships have also been known to sail better, when clean stone ballast has been newly taken on board, than they have done after it had lain a long time in the hold, clogged and consolidated together: and this has entirely proceeded from the pliability of the bottom of the ship having been previously less confined by the ballast before it had formed a solid congealed mass upon it. Even the fresh stowing of iron ballast, has for the same reason been found to improve sailing. The most lively, cleanly, and desirable of all ballast for ships, is, water in casks, or else in tanks; but not filled quite full, so that the water may have room to move but a little, and acquire a sort of life and motion, operating in union with the pliability and motion of the ship.

125.—The vertical position of the sails merits the especial attention of the nautical officer, since in that respect they have a peculiar good effect, particularly when a ship is going large. The lower part of the square sails, in midships and afore it, should be carried as far forward from a perpendicular, as circumstances will admit, in order that the subsidence of the after-body may be the less prevented; and the bow the less depressed by the force of the wind upon them. Merely the lowering of the square sails a little, has been observed to accelerate the speed of a ship when she has been scudding before the wind. This is owing to the sails then flowing up, and to the impulse of the wind upon them operating with an upward force; and thus not only lessening the depression of the bow, and facilitating the subsidence of the after-body, but also co-operating with whatever effect that might happen to accrue from the action of the water as consequent on her velocity, in the lightening her over the fluid: (see art. 42 and 117.)

126.—It certainly appears very curious, on what minute delicate points the trim of ships, (or their *cue* if such an expression is allowable,) and their greatest rate of swiftness seem often to have depended. The fresh setting up of the shrouds is commonly known to make half a knot difference. And old experienced sailors have

sometimes been found out in cunningly putting a stopper on the main-stay, and confining it down to the deck, with a view to lessen the speed of the ship, and save themselves the trouble of taking in sail, when she has happened to have had a convoy in charge, and heavy sailing vessels falling astern. Suspending a weight on the main-stay, and not suffering the stay to be too taught, has been frequently observed to make a ship go much faster. And slacking the backstays a little, is very commonly found to improve sailing. And many other such circumstances could be related, that has excited the observations of mariners, which appeared of a very trifling nature, and yet have caused a material difference in the speed of ships; and it is now expedient to explain in what manner they operate to affect the velocity of a ship.

The advantage of raking the masts in the accelerating the speed of a ship, has already been exemplified, (see art, 113;) and the circumstances just above mentioned, all operate in conjunction with the raking of the masts, in producing this advantageous effect. And when the masts happen not to rake, these operations still have of themselves a tendency in promoting the speed of a ship, only there being no co-operation from the masts in consequence of their not raking, the effect is not so great. The co-operative effect can be made to appear very obviously: by raking the masts and letting the stays be a little slack, with a weight suspended on the stays, the masts acquire a spring or play aft; and the weight of the masts, sails, and rigging, overhanging a little aft, and being thus not strictly confined by the stays, from playing aft, hang back and produce an elastic resistance against the force of the wind, while the easing of the backstays, and letting the shrouds be rather slack, allow the masts play forward. The force of the wind on the sails, by thus operating in the first instance against the overhanging weight of the masts, sails, and rigging, to bring them upright, and to press them forward, has, in consequence, a less effect in lifting the stern, and in depressing the bow, than it would otherwise have, if the backstays and shrouds confined them from yielding forward, and thereby causing the wind to operate with a full and instantaneous effect in the lifting the stern and depressing the bow. Now it has been shown (see art. 123) that any thing which has a tendency to prevent or lessen the subsidence of the after-body, or which is the same in effect, to lift the stern, tends also to the depressing of the midship bend, and thereby to enlarge the area of resistance, and of course to increase resistance and impede velocity. Consequently, this elasticity acquired from the masts and rigging, allowing the pliability of the vessel to operate, and the after-body to subside, obviates this additional resistance, and improves her sailing; and not only in this respect, but by lessening the depression of the bow, whereby the body is lightened over the fluid, her speed is still further promoted: (see art. 117.)

127.—In what manner these circumstances operate so intimately

and importantly on the speed of ships will be by this developement very obvious: and if those to which allusion has been made, and other similar ones, were judiciously attended to, the sailing of most ships might be improved. But their operation not being comprehended, or rightly understood by mariners, the process being imperceptible, or at least, unseen by them, they have devoted their efforts to experiments in finding out the trim of ships; and their success has consequently usually been a matter of mere chance; or of discovery purely accidental. To the fortuitous operations of such circumstances, may often be attributed the cause of one ship happening to sail better than another, when both have been built from the same draught: some of these circumstances, or similar ones, have operated accidentally, and unobserved, in one ship, and not in the other. And hence also, why a sudden and apparently unaccountable difference in the sailing of the very same ship is so often experienced: it has arisen either from some difference in the vertical position of the sails, or something or other else has been casually done at times, which has promoted or perhaps restricted, either the pliability of the ship or the elasticity of her equipment.

128.—Pliability and elasticity should therefore be promoted in every possible degree. To further such views, each mast of a ship might be wedged in an iron collar, to which collar strong springs were securely attached, and the collar with its springs fitted in deep partners, so as to play freely and safely in them; this would render the motion of the masts more gentle, and yielding to the pliability of the ship; not only so, but by easing the jerking of the masts, the ship would be the less strained by them. All the blocks that are attached to the ropes or sheets which hold on the sails might be contrived to have springs: a spiral spring, in a short iron tube, similar to what is used for weighing articles, by lifting them up with it, might unite the hook to the strap of the block. These springs would operate, by applying at all times to the motion of the ship, the varying impulses of the wind on the sails more equally and constantly. This effect may be more clearly apprehended, by supposing the wind to be fluctuating, or to blow alternately with greater, and then suddenly with lesser force; the spring retains, and continues for an interval to apply the greater force of the wind, after its power has abated; and in such manner to operate during the varying of the impulses of the wind on the sails, the power reserved is communicated alternately as received, and the velocity of the ship promoted by the effect. India rubber, or caoutchouc, cut in strips, and in a stretched-out state, laid in with the yarns in the making of ropes, contributes very much to the elasticity of cordage, and in this view might possibly render it more advantageous for ropes, attached to the holding on of sails, at least, for so long a time as the elasticity produced might be retained.

In conclusion, every thing that contributes to facilitate the pliability of a ship, or to add elasticity to her masts, rigging, and

equipment will improve her sailing. It gives her a sort of life and spring of action, imitating the perfections of the animate productions in nature,—the exquisite works of nature's God!

THE END.